Influence of tectonic regime in the selection of ground motions for seismic site response analysis

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Abstract

The common practice in seismic site response simulation is to use the ground motion records consistent with the tectonic regime. In other words, for sites located in a stable continental region, ground motions recorded in a region with the same tectonic setup is used in computing the site response. In the present study, an attempt has been made to test the applicability of different ground motions in the simulation of local site response for a stable continental region. The numerical study was performed by using 140 ground motions recorded in stable continental areas and 150 ground motions recorded in active areas. The earthquake events with magnitude in the range of M_W 5 - 8 and distance 1-300km (active) and 1-500km (stable) were chosen. The magnitude range was further categorized into various magnitude bins with a variation of 0.5 and distance bins with a variation of 50km. The ground motions were selected in such a way that there exist at least 5 - 7 ground motions in each combination of the magnitude and the distance bin and recorded at a site with $V_S > 760ms^{-1}$. The soil profile was chosen from Gandhinagar, Gujarat, Western India, which is an intraplate region. The seismic site response of this site was studied in the form of predominant period and the amplification. The variation of these parameters in different scenarios was evaluated. The spectral amplification observed for ground motions from both the tectonic regimes has been compared. The results reveal that the predominant frequency of the soil deposit varies between 0.3-0.4s depending on the induced strain by the input motion. Also, the difference in the performance of the soil deposits to the ground motions is evident in the amplitude. Overall, the present study is an attempt to address the merits and demerits of using ground motions of the active tectonic regime in a stable continental region.

Keywords: Predominant site period; Amplification factor; Ground response simulation; Intraplate region.

1.Introduction

The significance of site effects has been amply demonstrated in the past earthquakes such as Kutch (1819), Michoacan (1985), Bhuj (2001), Sendai (2015) and many more. The practice of computing the effect of local sediments on the seismic waves traveling from a depth to the surface has evolved into more complex computations over the years. There is a constant effort to reduce the uncertainty in the overall response simulation thereby improving the accuracy of the estimates. The sources of uncertainty in Site Response Analysis (SRA) are mainly from the soil parameters and ground motion parameters. The parametric studies by [1] and [2] has revealed that the output parameters such as site amplification and response spectra are more sensitive towards the variability in the input ground motion. The use of multiple ground motions in SRA causes the difference in induced nonlinearity in the soil, as a result, a higher variance can be expected in the estimated response spectral parameters. Hence, more importance is given to the selection of ground motions for SRA.

The first and foremost criterion for the selection of ground motions for performing SRA is the tectonic regime. The tectonic conditions of the ground motion records must be consistent with that of the region for which SRA is being performed. The inherent difference in the two tectonic regimes i.e Stable and Active region is the attenuation characteristics (Q factor), stress drop, and kappa (κ). It is observed that the earthquakes in Stable Continental Regions(SCRs) behave differently in space and time as compared to active regions depending on the geometry of the seismic sources and stress accumulation. The frequency of earthquakes is less but more damaging in SCRs compared to that of Active regions and mostly shallow focused. Owing to the rare occurrences of earthquakes in SCRs, the availability of ground motion records is very less. As a result, the conventional practice is to choose ground motions records from other parts of the world with a similar tectonic setup. In spite of this arrangement SCRs still suffer from a lack of accurate and reliable data and hence, the motivation behind this study.

The present study is an attempt to understand the difference in the ground motion characteristics of SCRs and Active regions. An investigation has been carried out to evaluate the difference in the site response computation when ground motions of different tectonic regimes are applied in the simulation. In this regard, a site located in Gandhinagar, Gujarat, Western India (an intraplate region of India) were chosen. The SRA has been performed for each individual soil profiles from the three sites using ground motions of different tectonic conditions. The objective of the study is to identify the difference in the estimated parameters from SRA when ground motion recordings from diverse global sources of different tectonics are applied.

The performance of each of these ground motions in terms of spectral amplification is assessed in the multidimensional frames consisting of Magnitude (M_W), distance (R_{epi}) and spectral period. Further, the response spectrum generated at the surface level as well as the fluctuation in the peak acceleration along the depth of the soil profile is compared for different suites of ground motion. Overall the present study attempts to understand the science behind the fundamental criteria for ground motion selection and suggests a statistical compensation to overcome the criteria.

2. Input parameters

The input parameters required to perform SRA are the dynamic properties of the soil and the input motions to simulate the propagation through the layered deposit. The soil properties necessary for modeling the dynamic behavior of the medium are unit weight, shear modulus reduction (M-R) and damping (D) curves. These properties are derived from the site investigation and laboratory experiments on the sample procured from the site. In the absence of sophisticated laboratory facilities, standard M-R and damping curves developed elsewhere for different soil types are adopted in order to capture the dynamic behavior. In the present study, the curves proposed by [3] were used to model the shear modulus and damping. The shear wave velocity (V_S) and unit weight (γ) of soil profiles were obtained from site investigation. The soil profile analyzed in the study has been shown in Fig.1. The predominant soil type is silty sand with few layers of clay of intermediate plasticity. The V_S was determined up to a depth of 30m from the P-S logging seismic technique and the borehole was terminated upon reaching a harder stratum (stiff Clay). The average shear wave velocity of the soil deposit is $365ms^{-1}$.

The input motions to which the modeled soil will be subjected to were selected based on multiple criteria. ASCE/SEI 7-05 [4] mandates the selection of pairs of ground motions from individual recorded events having magnitude, site-to-source distance, and source mechanisms that are consistent with those that control the ground motions at the site. However, it is preferred but not mandatory to select ground motion records of sites with the same site conditions such as soil type as that of the site of interest. The standard procedure is to select a minimum of 5 to 7 ground motions to reduce the epistemic uncertainty in the estimation. In the present study, ground motion records from various tectonic regime i.e SCR and Active region and recorded at sites with $V_S > 760ms^{-1}$ was selected. The magnitude and distance range chose for the selection were M_W 5-7 and R_{epi} 0-300km respectively. The selected ground motion records were categorized into multiple bins of various magnitude-distance combination. Magnitude-wise, the bins were categorized with an interval of 0.5 and distance-wise with an interval of 50km. The ground motion records selected for the study have been shown in Fig. 2. As evident from Fig.2, the ground motion records have been chosen from multiple sources. Most of the ground motion records representing SCRs were chosen from the European and PEER database whereas for Active region the records have been taken from the PEER database alone. Upon logistical evaluation of the collected ground motion records, it was observed that the significant number of records were not available from SCRs for $M_W >$

6.5 and from Active region for intermediate distance bins 150-300km in the M_W range of 5.5 – 6.5. Hence, statistical comparison and tests have not been performed for those bins with records of insufficient numbers. The modeled soil profile coupled with the input motions were analyzed for computing the site response using SHAKE 2000 platform [5].

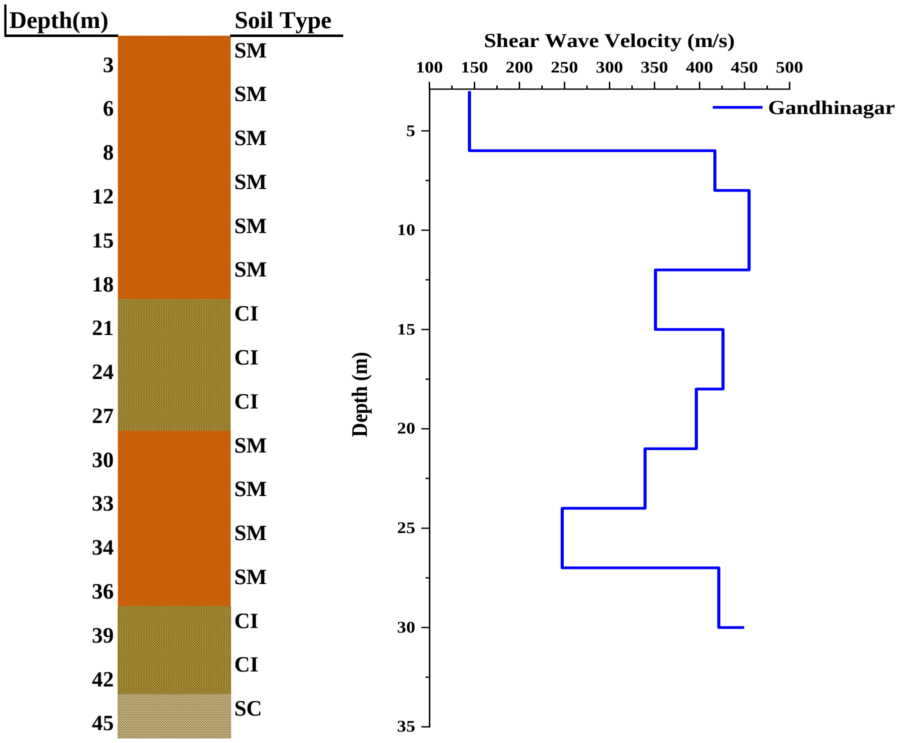

Fig. 1: Stratigraphy and shear wave velocity (V_S) profile of a site located in Gandhinagar.

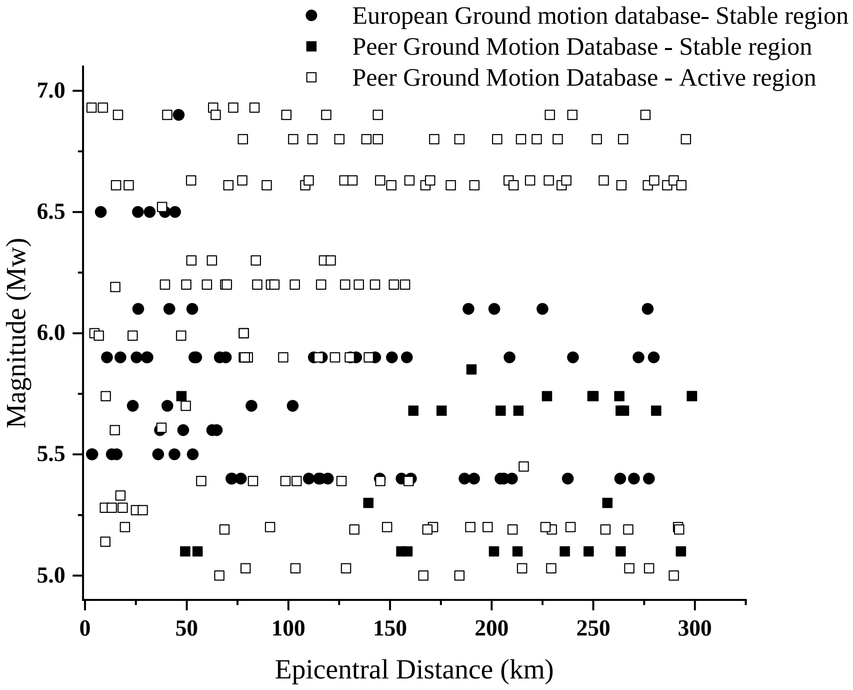

Fig.2: Ground motion records used in the study.

3. Computation of seismic site response

The site response has been computed by considering the 1-dimensional wave propagation of Shear waves in an equivalent linear soil model. A minimum of 5-7 ground motions is mandatory for a reasonable estimate of site response output parameters. In the initial screening process, the bins (a combination of M and R) with ground motions less than 5 were not considered for analysis. In this regard, the bins in the M_W range of 5 – 5.5 had 7 ground motions each from SCRs and Active regions across all distance bin ranging from 0-300km. Further in M_W 5.6 – 6 and 6.1 - 6.5, only three bins (R = 0 – 150km) satisfied this criterion. The analysis was not carried out further for seismic events with $M_W >$ 6.5 as significant records were not available from SCRs for these bins. In conclusion, the same soil deposit has been subjected to a suite of ground motions recorded in SCRs and Active regions. Since each bin consists of a minimum of 14 ground motions from both the suites, a total of 168 analyses have been performed.

When the ground motion travels through various soil strata, the characteristics of the seismic wave such as amplitude and frequency content undergo modifications. These modifications are highly dependent on the intensity of the input motion, geometrical and dynamic characteristics of the soil medium. The characteristics of the earth material vary from hard rock (at depth) to soft soil (at the surface). The seismic waves travel faster in harder stratum and slow down in softer deposits leading to an increase in the amplitude of the seismic wave due to the accumulation of the energy. Hence, softer deposits amplify the seismic wave more than hard strata. The spectral amplification (AF) i.e ratio of Spectral acceleration at the surface to that at the base is one of the critical aspects of SRA. The amplification caused by the soil deposit to different suites of ground motion i.e Active and SCRs has been compared in fig.3.

The amplification behavior of the two ground motion suites across the whole range of spectral period under different earthquake scenarios has been demonstrated in Fig. 3. Based on the observation from fig. 3, it is safe to say that the amplification primarily depends on the intensity of the input motion rather than the tectonic conditions. The ground motions have offered lower and higher-order estimates of amplification irrespective of their tectonic origin. The fundamental period of vibration of the soil column is nearly 0.33s. Hence, peak amplification can be observed in the period range of 0.3 – 0.4s. However, a significant shift in the predominant period has been observed for high-intensity ground motion records with PGA > 0.5g depending on the induced strain. Higher amplification was observed for a few records with a lower value of PGA. Hence, it was found that the amplification is sensitive to level of input ground motions. Further, studies have revealed that PGA alone is not a sufficient predictor variable for amplification [6] and hence, concluding the amplification behavior based on PGA alone is not rational. The amplification behavior of the Active and SCR conditions seems to follow a similar pattern at periods > 0.1s.

A similar comparison has been done for other magnitude and distance bin as shown in Fig. 4. The amplification pattern demonstrated by the SCRs and Active region is quite similar. Higher variability was noticed between few records near the fundamental period of vibration of the site and hence, a slight difference in amplitude can be witnessed. Overall it can be said that the ground motion records from Active region amplify 50-60% more than that of the records from SCRs near the site natural period in certain cases. On the other hand, it was observed that records from SCRs amplify 20-40% more than the Active region at certain spectral periods. At spectral periods beyond the natural site period, the average amplification of both the ground motion suites is more or less the same except at nearby distance $R_{epi} <$ 50km.

A Whisker box plot indicating the variation of spectral amplification has been plotted in Fig. 5. The plot reveals the median (horizontal line inside the box), mean (dot inside the box), 2nd, 25th, 75th and 95th percentile of Spectral amplification. It is evident from Fig. 5 that the difference in the estimated parameter is high between the two tectonic regimes for nearby distance with $R_{epi} <$ 50km. The ground motion records from SCRs have demonstrated higher variability. As the distance increases i.e $R_{epi} >$ 50km, the estimation from the two tectonic regimes is similar and comparable.

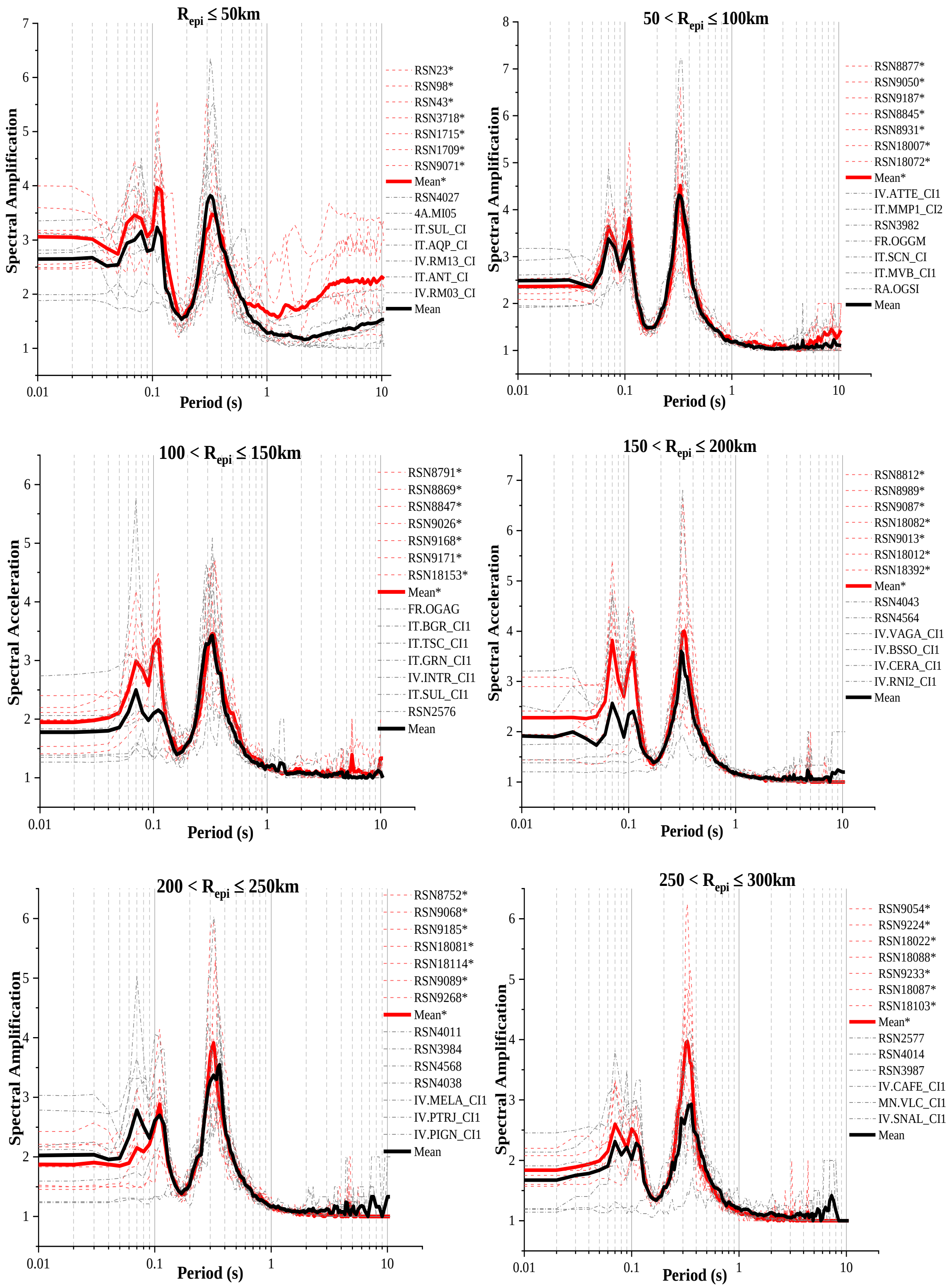

Fig. 3: Comparison of amplification pattern between ground motion records of SCRs and the Active region with M_W 5.1 – 5.5.

[*Ground motion records from the active region; solid lines indicate the mean of their respective ground motion suite. Red lines – Active region and Black lines – SCR.]

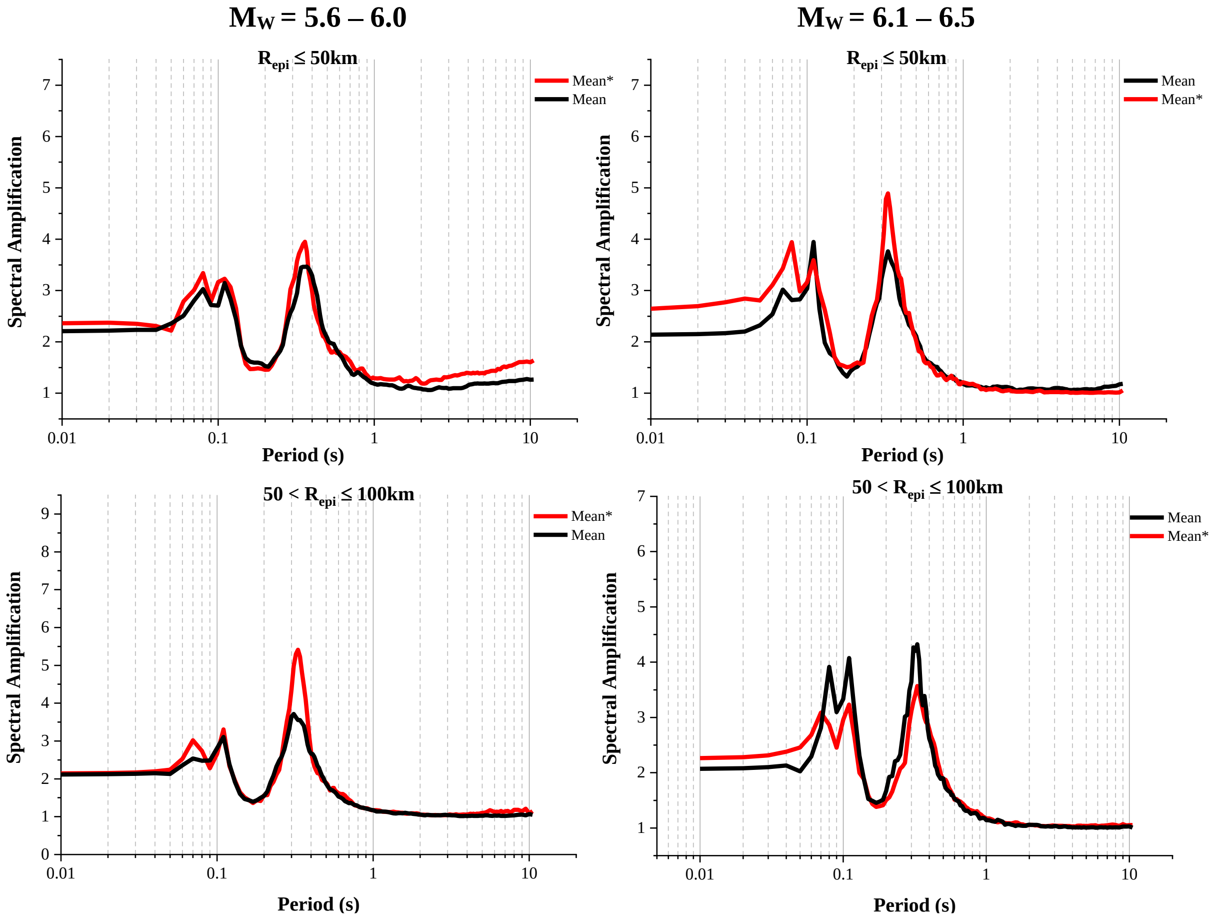

Fig. 4: Comparison of spectral amplification for input motions in that range of MW 5.6-6.0 and 6.1-6.5 and distance ranging from 0 to 100km. [Note: Redline – Active region and Blackline – SCR]

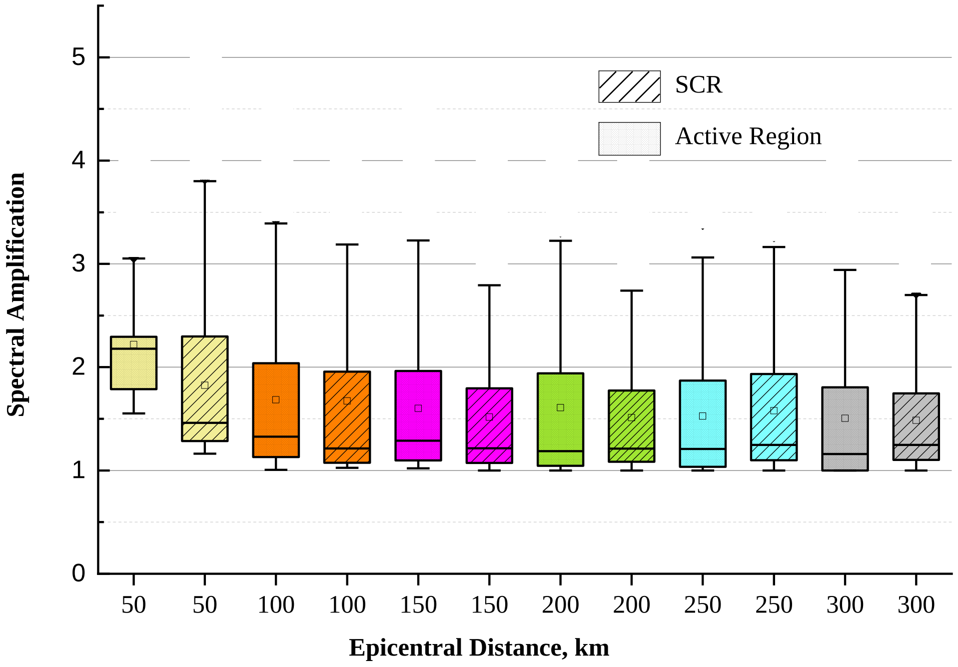

Fig. 5: Box plot indicating the mean, median and the percentile distribution of Spectral Amplification.

The response spectrum generated at the Surface level by different input motions constituting the two different suites i.e SCRs and Active región has been presented in Fig.6. The spectral shape and the amplitude estimated by both the input motion suites trace the same pattern with varying amplitudes. Since the maximum value of spectral acceleration has been observed in the same period range by both the suites, it can be said that the tectonic regime is not an influential parameter during the selection of ground motion records. However, the ground motion records from Active región tend to overestimate the spectral parameters as compared to SCRs. This can be attributed to the fact that the ground motions recorded in SCRs are rich in high frequency and tend to attenuate faster as a result amplification is less. Further, buildings with natural period > 1s are not affected by the tectonic origin.

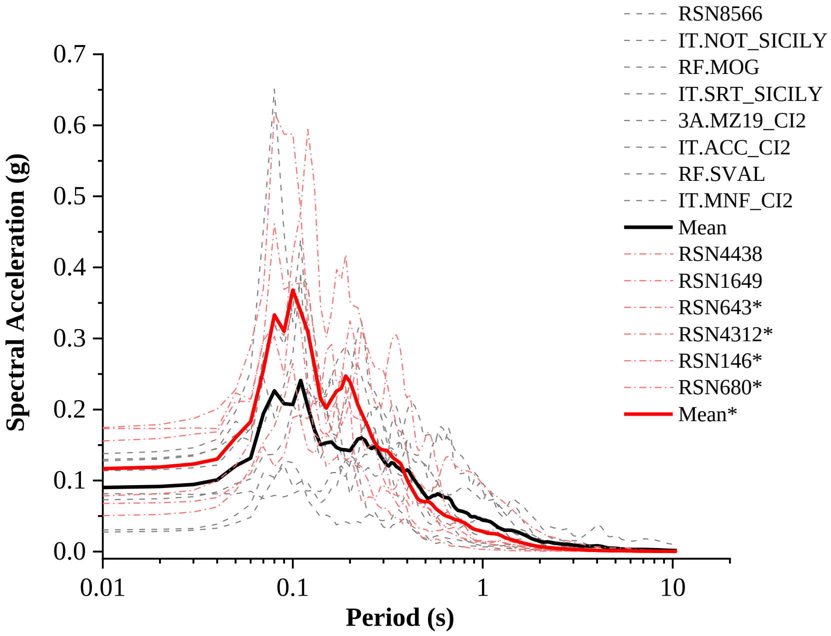

Fig. 6: Comparison of the response spectrum generated at the surface by the two ground motion suites. *Ground motion records from the active region; solid lines indicate mean of their respective ground motion suite. Red lines – Active region and Black lines – SCR.

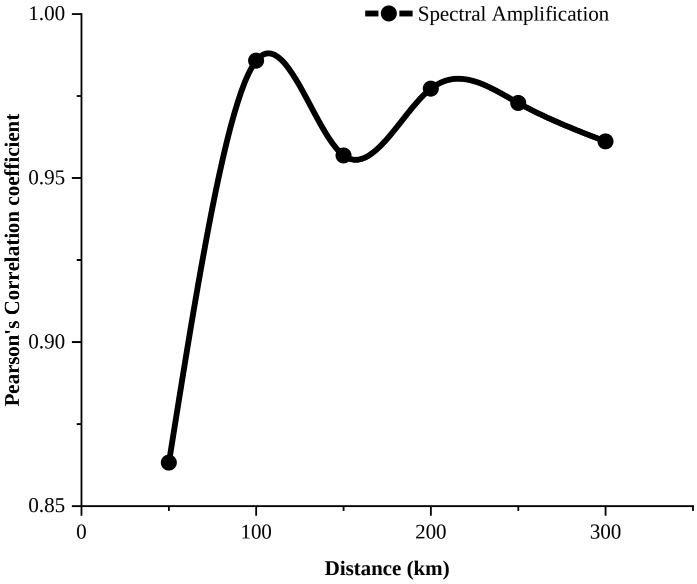

Fig. 7: Plot of Pearson's correlation for different epicentral distances within M_W range of 5.1-5.5.

In order to further strengthen our claim, Pearson's correlation test was performed for the average spectral amplification estimated by the two ground motion suites. The correlation coefficient as a function of distance within a given magnitude range i.e M_W 5.1-5.5 has been presented in Fig. 7. A correlation coefficient of 0.86 (for R_{epi} < 50km) and greater than 0.92 for distances between 51-300km was observed. These values imply that there exists a strong and positive correlation between the two analyzed time series. A similar statistical test was performed for the response spectrum generated by the two ground motion suites. The tests revealed the coefficient value as 0.98 indicating a positive correlation. Hence, the spectral amplification and the response spectrum are independent of the tectonic origin of the input motion.

4. Conclusions

The present study was an attempt to test the applicability of ground motions recorded from an Active region in a Stable Continental Region. In this regard, two ground motion suites consisting of records from Active region and SCRs were constructed and SRA was performed. The outcome of SRA has been studied in terms of spectral amplification and response spectrum as most of the building codes rely on these two parameters for quantifying the site effects. The studies reveal that the spectral amplification and the response spectrum are independent of the tectonic origin of the input motions. Further, the ground motions from the Active region tend to overestimate the spectral parameters when compared to ground motions from SCRs. In order to quantify the parameters affecting the max amplification, the study suggests performing statistical tests in the Fourier domain. Overall, it can be concluded that the effect of the tectonic regime in the selection of input ground motions for site response analysis is insignificant and an exact correlation between the two tectonic origins can be derived and implemented.

5. Acknowledgments

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6. References

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