Spatial Correlation of Ground-Motion for Napa earthquake

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Abstract

The probability of joint occurrence of ground motion intensities at multiple sites during the same earthquake needs to be quantified in aggregated seismic risk analysis or loss assessment. The spatial correlation of ground motion at multiple sites cannot be considered in conventional specific-site seismic hazard analysis method. In this paper, the spatial correlation of ground motion is studied using 344 sets of strong earthquake records from the Mw6.0 Napa earthquake, California, US on August 24, 2014. The spatial correlation functions of the peak ground acceleration (PGA), the peak ground velocity (PGV) and response spectrum values at three specific periods (0.3, 1.0 and 3.0 seconds) are derived using the method of semivariogram function. The corresponding continuous spatial correlation function is fitted by exponential model and compared with the previous research results. The analysis results show that the ground motion parameters are spatially correlated, and these spatial correlations exponentially decay as the distance increases. Secondly, the spatial correlation of ground motion increases with the increase of response spectrum period. Finally, there is a regional characteristic in the spatial correlation of ground motion. It can provide theoretical basis and reference for aggregated seismic risk analysis or loss assessment and reducing uncertainty for ShakeMap in the future.

Keywords: Napa earthquake, the ground-motion, spatial correlation, semivariogram

1. Introduction

The traditional seismic hazard probability analysis method of specific site has been widely used in seismic zonation and seismic hazard assessment of major engineering sites. However, the seismic hazard analysis method of specific site is obviously not competent for engineering applications that need to know the simultaneous occurrence probability of ground motions of multiple sites [1-3]. For example, the probability, that the seismic intensity of multiple sites is jointly exceeded, needed to be estimate for life-line engineering of space distribution, aggregated seismic risk assessment and loss assessment. The spatial correlation model of seismic motion among multiple sites is beneficial to develop the seismic hazard assessment or loss assessment of seismic hazard or risk analysis from specific site to multiple sites.

In recent years, the research about spatial correlation of seismic ground motion parameters has attracted much attention in seismology and engineering seismology. Goda and Hong[4]studied the spatial correlation of PGA, PGV and three acceleration response spectral values using observations from Southern California and Chi-Chi earthquakes in the United States. Using more intensive sk-net, k-net and kik-net seicmic data, Goda and Atkinson[5-6] studied the seismic spatial correlation of different types of earthquakes. Jayaram and Baker [7] studied the spatial correlation of spectral values of the Northridge earthquakes and five other earthquakes. Sokolov et al.[8] studied the spatial correlation of ground motion using observation data of different sites and stations arrays in Taiwan. Esposito and Iervolino [9-10] studied the spatial correlations of PGA, PGV and different response spectral values by combining data from the European ESD and Italian ITACA. Recently, Pavel and Vacareanu [11] investigated the spatial correlation of the response spectral values (less than 3 seconds) for the central and deep source earthquakes in Romelia.

This paper collects intensively observed station data from the 2014 Napa earthquake in Southern California, and preliminarily studies the spatial correlation of ground motion. the spatial correlation functions of peak ground acceleration (PGA), peak ground velocity (PGV), and acceleration response spectra with period 0.3 s,1 s, and 3 s (indicated as sa (0.3 s), sa (1.0 s) and sa (3.0 s), respectively) were derived using the mothed of semivariogram function. We hope that it can provide reference for the lifeline engineering and aggregated seismic risk assessment and loss assessment. On the other hand, considering the spatial correlation of the seismic motion can further reduce the uncertainty in ShakeMap following the earthquake.

2. Data

On August 24, 2014, an *M*w6.0 earthquake struck Napa, California, with a epicenter of 38.22°N, 122.31°W and a focal depth of 12km. This earthquake was the largest in the San Francisco Bay Area since the 1989 Loma Prieta *M*w 6.9 earthquake. the reliability of the ShakeMap for PGA under different constraints have been researched, using 344 strong ground motion records obtained from the engineering strong ground motion data center (CESMD) [12]. The geometric mean values of two horizontal components of each station for the PGA, PGV, and three specific periods response spectra (Sa (0.3 s), Sa (1.0 s) and Sa (3.0 s)) were obtained using these seismic records. The spatial distribution of the station is illustrated in figure 1, and the projection surface of the fault rupture on the surface come from the research results of finite fault inversion [13].

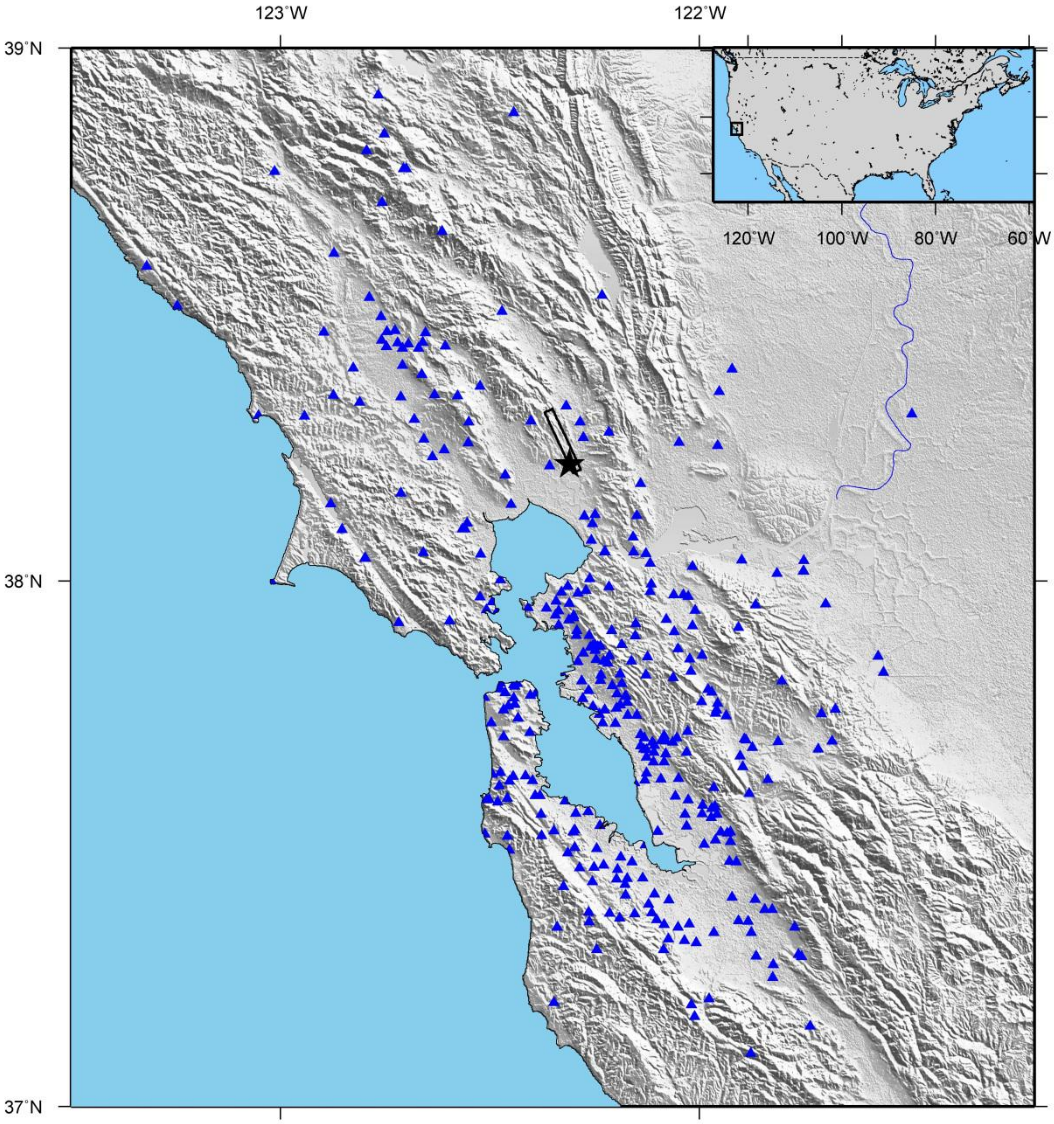
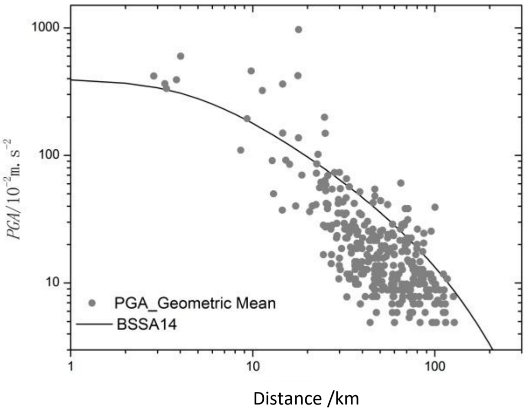


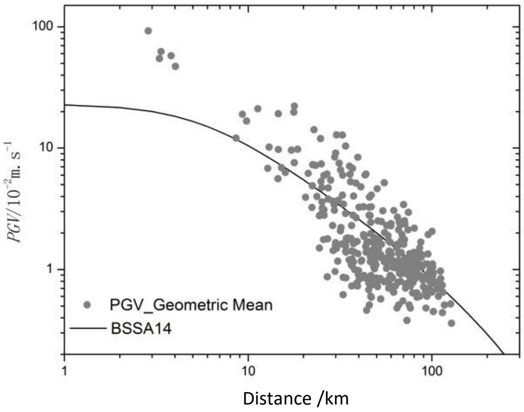
Fig. 1 Spatial distribution of the ground motion observations in Mw6.0 Napa earthquake on 24 August 2014

(The blue triangle represents the seismic station, the black star shows the epicenter of Napa earthquake, the black square indicates the surface projection of the rupture plane, and inset block shows location of the research area within US.)

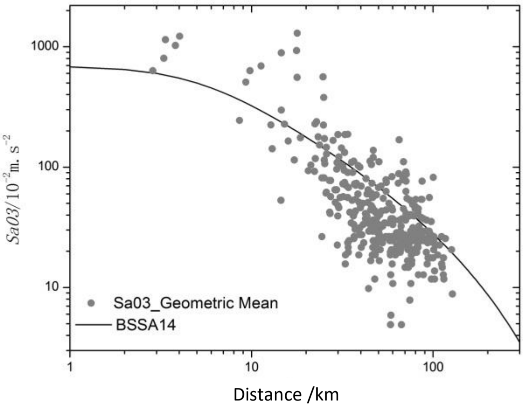
The seismic ground motion attenuation relation of Boore in NGA-West2 [14], referred to as BSSA14, was used in this study. Local site conditions can have a significant effect on the ground motion parameters recorded by the station. Using the correlation of topographic slope with vs30 (average shear wave velocity from surface to underground depth of 30 m), site magnification factors about ground motion with different amplitude and frequency are obtained [15-17]. The site magnification factor was used to convert the ground motion of the surface observation of the station to the bedrock reference surface. The fault projection distance between each station and the fault projection surface is calculated and compared with BSSA14. These results are shown in figure 2. In addition, the logarithmic residual distribution of the station observation data and BSSA14 attenuation relationship is shown in Fig.3. It can be seen from figure 2 that the dispersion between each ground motion parameter and BSSA14 is large. These stations are mainly located in the range of 20-100 km from the projection plane of the fault. More than 300 stations are densely distributed in the range of 20-100 km, which also provides a prerequisite for the study of the spatial correlation of ground motion in this paper. From the residual distribution of figure 3, it can be seen that the BSSA14 attenuation relationship underestimates the ground motion of the high-frequency component, and the residual value of the PGA is mostly negative. Whereas the acceleration spectral values of 3-second are basically distributed around 0 values.



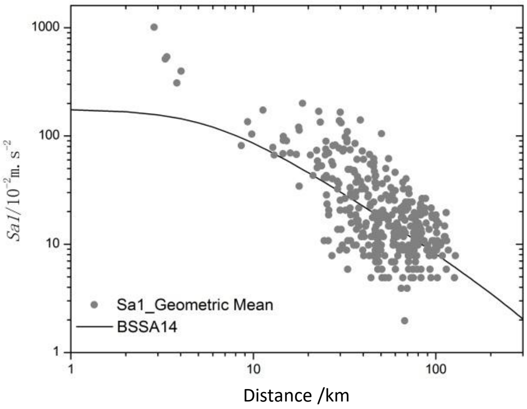
a.PGA



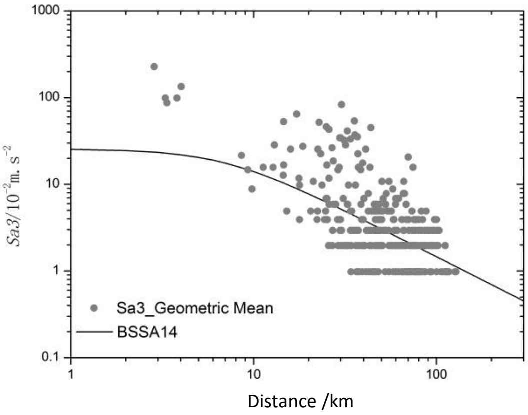
b.PGV



c.Sa(0.3s)



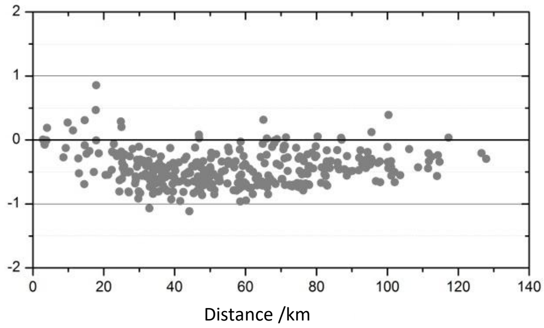
d.Sa(1.0s)



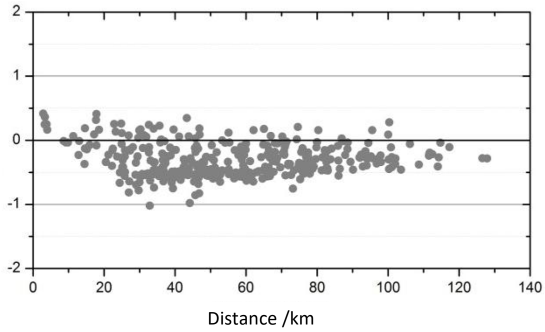
e.Sa(3.0s)

Fig. 2 Ground motion observations of Mw6.0 Napa earthquake on 24 August 2014 compared with GMPE

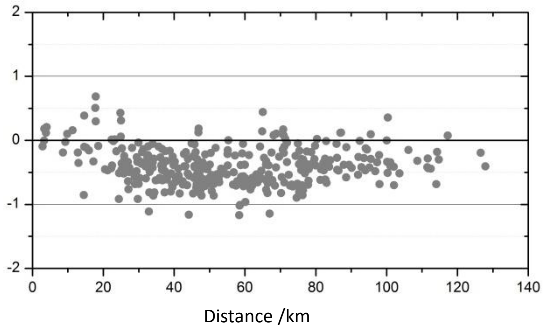
(a. Peak Ground Acceleration (PGA);b. Peak Ground Velocity (PGV);c. response Spectral Acceleration values at 0.3 second periods (Sa(0.3s)); d. response Spectral Acceleration values at 1 second periods (Sa(1.0s)); e. response Spectral Acceleration values at 3 second periods (Sa(3.0s)).)



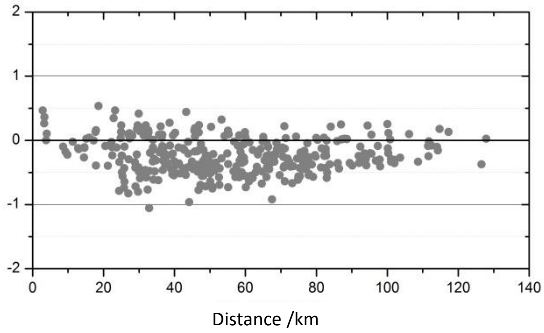
a.PGA



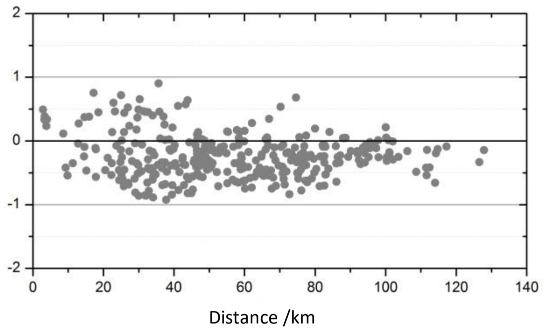
b.PGV



c.Sa(0.3s)



d.Sa(1.0s)



e.Sa(3.0s)

Figure3. Intraevent residual plot for ground motion parameters

(a. Peak Ground Acceleration (PGA),b. Peak Ground Velocity (PGV),c. response Spectral Acceleration values at 0.3 second periods (Sa(0.3s)), c. response Spectral Acceleration values at 1 second periods (Sa(1.0s)), c. response Spectral Acceleration values at 3 second periods (Sa(3.0s)).)

3. Methods and Models

The experimental semivariograms are computed starting from the normalized intraevent residuals (the ratio between intraevent residuals and corresponding intraevent standard deviation) as shown in Jayaram and Baker [7] as equation (1)

$$\hat{\gamma}(\mathrm{h}) = \frac{1}{2N(h)} \sum_{\mathrm{i}=1}^{N(h)} \left(Z_{a_i} - Z_{\mathrm{b}_i}\right)^2 \tag{1}$$

In which N (h) represents the number of pairs of sites considered in the analysis, Z_{a_i} and Z_{b_i} are the normalized intraevent residuals computed at a separation distance h.

The sill of the semivariogram is equal to unity because the intraevent residuals have unit variance.Therefore; the spatial correlation coefficient is computed as equation (2)

$$\rho(\mathrm{h}) = 1 - \gamma(\mathrm{h}) \tag{2}$$

$$\gamma(\mathrm{h}) = \mathrm{a}[1 - exp(-3h/b)] \tag{3}$$

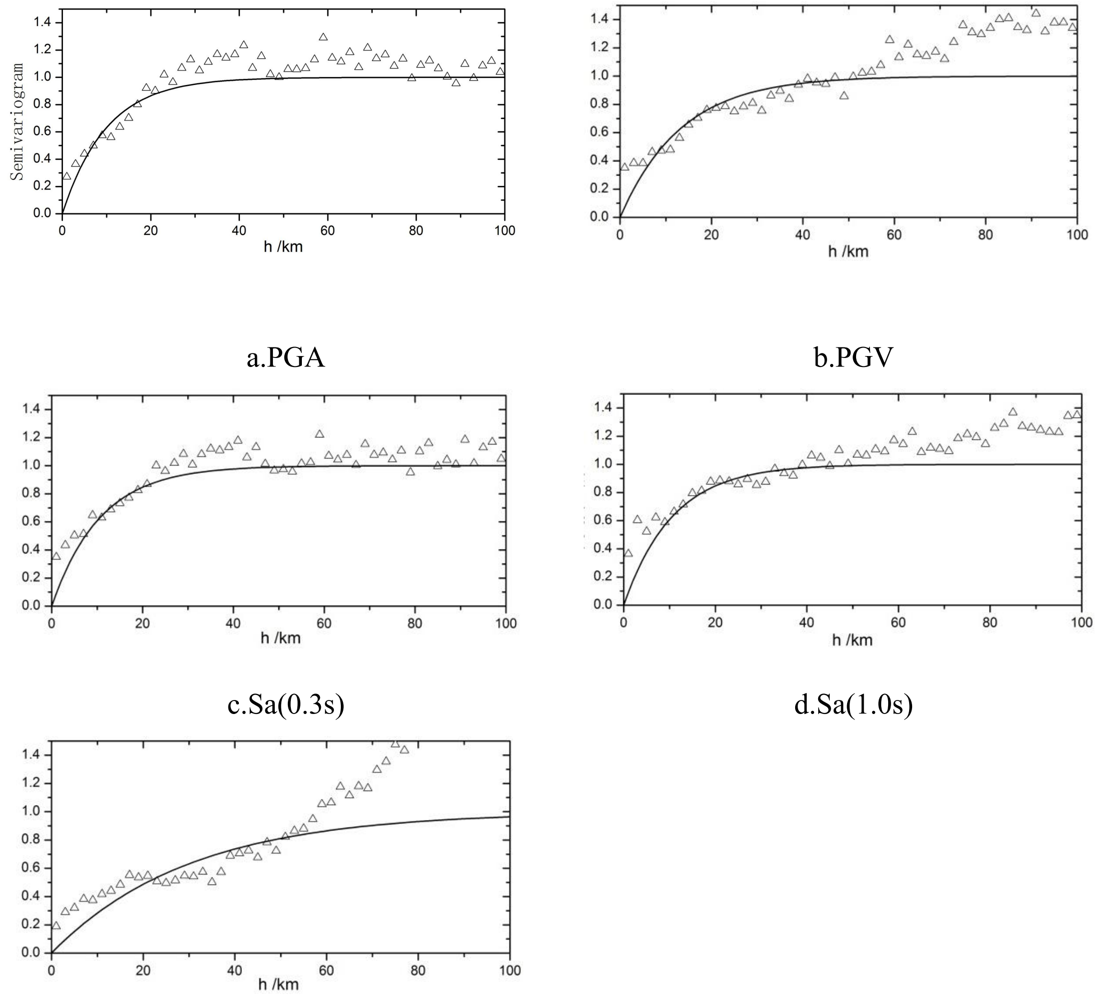
Generally, the exponential model, described in equation (3), is expressed as a function of the sill a and correlation range b [7].

4. Results and discussions

The spatial correlation of the seismic intensity of different sites can be expressed by a semi-variogram function. Figure 4 is a histogram of the number of pairs of nappa seismic observation stations vs the spacing distance of the stations. The distance between stations is 2 km, so that there are at least 120 pairs of data in each distance interval, which can ensure the reliability of statistics. Figure 5 shows the results of the semivariogram function for observed peak acceleration, peak velocity, and the three specific periodic response spectra according to equation (2), and which is fit according to the exponential model using the manual method. The range values of the exponential model fit are shown in table 1. the results of figure 5 show that the response spectral values of PGA, PGV, and three response spectra values are spatially correlated and approximately fellow the exponential distribution.

Table 1 Range fitted by exponential model in equation (4) for PGA, PGV, spectral accelerations at 0.3, 1.0 and 3.0s

Ground motion parameter	**PGA**	**PGV**	**Sa(0.3s)**	**Sa(1.0s)**	**Sa(3.0s)**
Range value	30	40	32	32	90



a.PGA

b.PGV

c.Sa(0.3s)

d.Sa(1.0s)

e.Sa(3.0s)

Figure5. The semivariogram of the Napa earthquake observation data and the fitting result of the exponential model

(a. Peak Ground Acceleration (PGA),b. Peak Ground Velocity (PGV),c. response Spectral Acceleration values at 0.3 second periods (Sa(0.3s)), c. response Spectral Acceleration values at 1 second periods (Sa(1.0s)), c. response Spectral Acceleration values at 3 second periods (Sa(3.0s)).)

The comparison results of the semivariograms constructed by different seismic ground motion parameters of Napa seismic observations are shown in figure 6. It can be seen that the growth rate of the semivariogram function becomes smaller and the spatial correlation becomes larger as the response spectra period increases. There is a stronger spatial correlation for long- period composition of ground motion than short-period (high-frequency) composition, also consistent with previous findings [18]. During the propagation of seismic waves, the similarity of seismic waves is reduced due to the scattering of the waves. The amplitude of the decrease in the propagation process is larger for high frequency seismic waves, probably because the short wavelength is more easily affected or changed by small scale heterogeneity.

Figure 7 shows the comparison of the peak acceleration correlation model mentioned in the previous literature with the nappa earthquake in this paper. It can be seen that the spatial correlation model of the Napa earthquake decays more slowly and has greater spatial correlation than that of the models of Esposito and Levolvino [10], Boore [19], Jayaram and Baker [7] and Goda and Hong [4]. There is a smaller spatial correlation for Napa earthquake than that of Pavel and Radu [11], Goda and Atkinson [5] and Sokolov [8]. It is worth noting that only seismic records in Southern California were used in the spatial correlation model of peak acceleration established by Boore [18], Goda and Hong [4], Jayaram and Baker [7], indicating that the spatial correlation of peak acceleration in Southern California is weaker than that in other regions. The research of Goda and Hong [4] also shows that the spatial correlation of peak acceleration of Chi-Chi earthquake is slower than that of California. Looking at the spatial correlation results of the peak acceleration of the napa earthquake carefully (figure 5a), we can see that the semivariograms constructed in this paper are above the fitting curve in the distance less than 10 km, which indicates that the spatial correlation at short distance should decay faster, and the overall fitting effect was taken into account in this paper. Results of Goda and Atkinson [5-6], Sokolov [8], and Pavel and Radu [11] attenuated more slowly than the spatial correlation of the Napa earthquakes, while the data they used come from earthquake of Japan, Taiwan, and Rumelia. It shows that the spatial correlation of seismic parameters has regional characteristics.

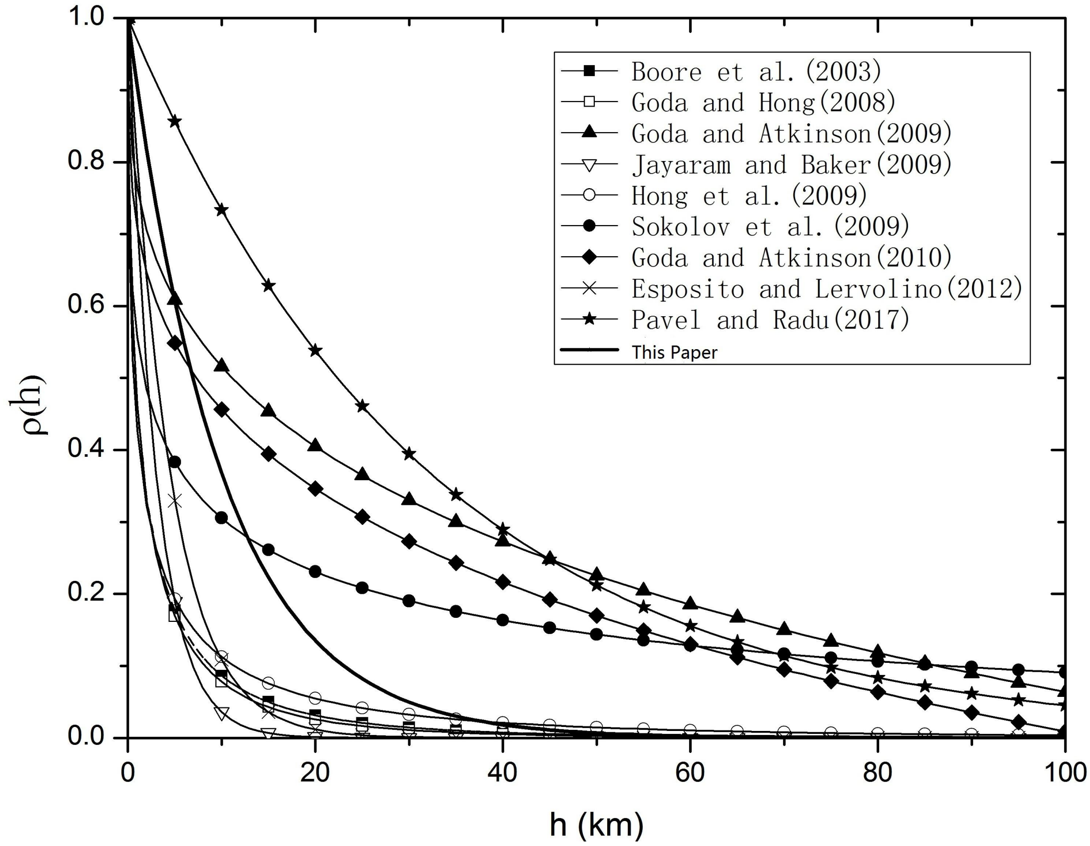


Figure7. Comparison between various correlation models for PGA available in literature and result of Napa earthquake

5. conclusion

In this paper, the spatial correlation of the random variables (ground motion parameters) is studied using the semi-variogram method. The spatial correlation model of the peak acceleration, peak velocity and three specific periodic response spectral values of the Napa earthquake is obtained. The results show that the spatial correlation of the ground motion parameters increases with the increase of the spectrum period. And the spatial correlation of ground motion parameters has certain regional characteristics, and the spatial correlation for the same ground motion parameters in different regions is different.

Compared with Southern California, Japan and Taiwan, the density of the ground motion observations networks in China is relatively sparse. It is not very reliable to study t spatial correlation of ground motion at short distance using seismic observation data in our country at present. However, with the further development of China's "seismic intensity quick report and earthquake warning" project, the spatial correlation model of ground motion parameters in China can be derived in the future.

6. Acknowledgements

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7. Copyrights

8. References

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