ACCURACY OF SEISMIC TREATMENTS ASSESSMENTS USING SOURCE MODELS

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ABSTRACT :

Today are a lot of publications devoted to seismic treatments assessments using the dislocation model of source. Sometimes the synthetic accelerograms calculated using this method even proposed to structure engineers for antiseismic design. The response spectrum of calculated accelerogram is accepted as a local (site - specific) design spectrum. Our investigation is dedicated to the estimating of accuracy of results obtained by such methods. The calculations are based on the model of the type of Haskell's solution, generalized to the case of the semi - infinite media. The near-field ground motion at the given site is computed using developed model of particular earthquake. Then a site -specific response spectrum related to obtained synthetic accelerogram is calculated. It is possible calculate the synthetic accelerograms and related response spectra using variability of the parameters of source model according to probability of source parameters realization. The influence of variability of source model parameters on the parameters of seismic treatments is considered. Independently (as it is accepted in the classic practice of seismic treatment assessment) the local (site - specific) design spectrum is constructed using the empirical data. The dispersion of strong ground motion parameters is known. Finally by comparison of the parameters of strong ground motion obtained using source model and the empirical ones it is considered the problem of the limits of application to use the discussing method in earthquake engineering.

KEYWORDS: source model, seismic treatment, response spectrum, accuracy, strong ground motion

1. INTRODUCTION

The strong ground motions due to earthquakes are important for the seismic hazard analysis. The lack of near-source records of strong ground motion generated interest to simulating such motions for purposes of engineering design [Famili, 2007; Shapira, Zaslavsky, 2007 etc.]. A lot of different models or different modeling techniques are known in the modern seismology. Earthquake source model based on the dislocation theory is now widely used in seismology [Haskell, 1964, 1969, Sato, 1972; Atkinson and Silva, 2000 etc.]. Still J. Anderson and P. Richards (1975) had showed that for the simulated time histories even in the near-field zone the different dislocation models are given very similar results. The main problem of ground motion prediction for seismic treatment assessments is the error estimation related to source model methods.

2. PREDICTING OF STRONG GROUND MOTIONS FOR SPITAK EARTHQUAKE, 1988, 7, DECEMBER

In this section are used the results of one of the authors obtained earlier [Cisternas, Dorbath et al., 1991]. The very simple and well known dislocation model was used– the dislocation model of the type of Haskell's solution [Haskell, 1964, 1969], generalized to the case of a half-space [Erteleva, Graizer, 1991]. The fault surface is represented as a rectangle with length L and width W; the source propagation starts simultaneously along the width of rectangular dislocation and spreads along the source length with constant velocity v. The fault displacement is represented by a ramp of Haskell’s type with following parameters: D is the maximum fault displacement, v is the rupture propagation velocity, T is the rise time of fault displacement at the source surface.

The fault parameters *D*, *v* and *T* are constant for every subsource. In solving direct problem the Haskell's formulas are used [Haskell, 1969] together with Steketee method ("true" source - "imaginary" source) [Steketee, 1958]: the motion at the plane due to the dislocation source is substituted by the sum of the effects of two sources which are symmetric relatively to the plane and located at the depths *h* and "– *h*"; and the stresses at the free surface due to the simultaneous effect of these two sources are calculated. For the elimination of the remaining stresses Lamb's problem is solved. Finally the movement of the half-space surface can be represented as the sum the Haskell's solution for the infinite medium, the disturbance due to the imaginary source at the depth "- *h*" and the solution of Lamb's problem. The obtained solution for displacements at the free surface of the half-space due to the dislocation source is rather complex and is completely written in paper [Erteleva, Graizer, 1991].

The proposed approach to the earthquake source modeling consists in the gradually complicating of the model (for example, from single dislocation model to a few subsources model). Model can be admitted as optimum if it permits to reach the best agreement between theoretical and experimental data. The local conditions are taken into account.

As example of using such technique of predicting strong ground motions consider the Spitak event, December, 7, 1988, using Gukasian station record. Seismological, geologic, tectonic and strong motion records data, space distribution of aftershock sequence and other observations permit to construct mechanical model of Spitak earthquake source. For the purpose of modeling the source representation as a planar rectangular dislocation or a number of dislocations in a homogeneous isotropic elastic half-space was used.

In the first step of modeling the Spitak earthquake source was represented as a simple plane dislocation with sizes S = 300 km^2 propagating with constant velocity without stops or other singularities. For the purpose of the objective estimation of agreement quality of theoretical displacements calculated for the proposed source model and integrated displacements using Gukasian record the correlation coefficients between obtained curves were computed (Table 1) for every component. As it is seen from Table 1 the displacements calculated using this simple model has not good correlation with ones obtained from real record. As a result it may be concluded that this simple dislocation model agrees only in general with displacements calculated using Gukasian accelerogram. According to this comparison it may be concluded that the fault process was more complex and it seems reasonable to develop the source model on the base of other solutions. As the next step the model proposed in [Estabrook, Pacheco, Nabelek, 1989] was used. This model is based on teleseismic data and consists of three subsources. Displacement computations made on the base of this three subsources model are demonstrated more similarities with experimental data than the previous one (see Table 1). The results of detailed field investigations of the surface ruptures, the configuration of aftershocks area, the analysis of teleseismic data and the determination of source mechanisms permit the construction of an even more detailed model of the Spitak earthquake source [Cisternas, Philip, Bousquet et al., 1989]. According to the analysis of these data the earthquake source can be represented as a combination of 5 bigger subsources. One of them is located at the well-known Pambak-Sevan fault. The average correlation coefficient with empirical data for this (5 sub-events) model is maximal.

Table 1 Correlation coefficients between the theoretical and empirical displacement curves

Model	Correlation coefficient			
	Component			average
	N-S	E-W	Z	
One-stage	0.725	0.126	0.0532	0.302
Three-stage	0.946	0.582	0.821	0.783
Five-stage	0.859	0.807	0.871	0.846

For the calculations the compression and shear wave velocities are considered to be 6 and 3.5 km/s, the velocity of rupture propagation - 2 km/s, and the rise time of the maximum displacement at the subfault surfaces - 0.5 s. The source time functions corresponding to each described models were developed.

Using the comparison of theoretical and experimental displacements it is possible to evaluate the average fault parameters of this earthquake. The average value of fault displacement is about 2.6 m. The total value of seismic moment is $2.3\text{x}10^{26}$ dyne/cm (the rigidity μ is considered to be $3\text{x}10^{11}$ dyne/cm^2. The evaluation of seismic moment made using different methods varies from $1.0\text{x}10^{26}$ to $2.4\text{x}10^{26}$ dyne/cm [Wyllie, Filson, 1989].

On the base of satisfactory agreement of theoretically computed and integrated displacements the model consisting of 5 subsources can be admitted. This model was used for predicting of near-source ground motion. Estimating ground motion in the completely destroyed Spitak city, in the vicinity of the fault surface traces, is certainly of the greatest interest. The theoretical computations made for Spitak demonstrate significant increase of amplitude (to 1m) in Spitak. On the base of these computations maximum amplitude of velocity in Spitak city can be evaluated of about 90 cm/s, and the amplitudes of accelerations - of about 0.3g. Perhaps, these evaluations of the displacement and velocity are reliable sufficiently, but the acceleration computation is corresponding to the lower estimation of wave amplitudes, since the calculations were made for the relatively smoothed source model disregard to peculiarities of low range of frequencies that are more significant for the accelerograms. Evidently waves of such amplitudes are destructive for most types of buildings and constructions. The theoretical calculations of ground motion were provided also for Kirovakan and Stepanavan cities. Obtained result is in agreement with data obtained earlier [Wyllie, Filson, 1989, etc.].

Then we computed the response spectrum with 5% damping for obtained simulated strong ground motions and estimated the predominant period, frequency bandwidth, duration, and PGA for the researching region (Table 2). The duration *d* (pulse width) we determine as time interval between the first and the last cases envelope amplitude is equal to half of maximum one. The logarithmic width *S* of spectrum is defined as the difference between the logarithms of the periods (or frequencies) of spectral half-maximum points (on the high- and low frequency slopes of the spectrum). But what is the accuracy of such estimations? It is unknown.

Now as it is accepted in the classic practice of seismic treatment assessment the local (site - specific) design spectrum is constructed using the empirical data. The comparison of the ground motion parameters of modeling and statistic spectrum is shown in the Table 2.

Table 2 Estimation of ground motion parameters using source model and statistics of empirical data for the Spitak earthquake

Town	A, cm/s^2		T_0, s		d, s		S	
	modeling	statistical	modeling	statistical	modeling	statistical	modeling	statistical
Spitak	300	694	0.25	0.36	4	2	0.82	0.58
Kirovakan	119	355	0.33	0.38	13	2.2	0.80	0.58
Stepanavan	72	269	0.25	0.36	2	2.3	0.61	0.58

We have obtained similar results for another earthquakes: Gazly (1976), Kum-Dag (1983), Neftegorsk (1995), Shikotan (1994). We estimate the approximate error of calculations for rock condition (to avoid the sediments influences): amplitudes 100%; calculated predominant frequencies for strong earthquakes up to 100%; duration is believed are the same for acceleration, velocity and displacement, due to this factor only systematic error is about 60%; frequency bandwidth is larger about 30% wide.

May be the reason of such discrepancy is the simplicity of using technique? Consider the similar results obtained using more complicated modern technique.

3. MODERN SIMULATING METHOD FOR PREDICTING STRONG GROUND MOTIONS

Several methods of source models are known in modern seismology to obtain various strong motion parameters. One of these methods is composite fault modeling technique, as shown earlier: synthetic accelerograms are simulated both by modeling the features of earthquake source process and using the wave propagation theory. This method gives very good results in modeling estimations of strong ground motion, but one requires the fault plane solution, the stress drop parameter, the velocity structure of region etc.

In another method empirical Green function is used: records of weak local earthquakes or aftershocks of the main event are used to simulate ground motion at observation point [Hartzell, 1978; Hadley et al., 1982; Irikura, 1983; Houston and Kanamori, 1984 etc.]. This method not requires the computation of the propagation and the local site effects, but requires the strong ground motion records of small events situated near the site for which predicting motion should be desired.

3.1. The Stochastic Simulation Technique

Now most popular is the stochastic simulation technique [Hanks and McGuire, 1981; Boore, 1983; Boore and Atkinson, 1987]. This method is based on the theoretical spectrum as seismological model of source and propagation process. In considering technique a band limited random white Gaussian noise is passed through number of filters representing earthquake process to get a synthetic ground motion. The source is divided into the sub-sources, each of which is then considered as a point source [Hartzell, 1978; Irikura, 1983]. It is used the envelope function which is defined the effect of rupture propagation, directivity and source geometry can influence the amplitude, frequency and duration of ground motion. The ground motion at the observation point is obtained by summing the contribution over all the subfaults. Beresnev and Atkinson (1997) used the method of stochastic simulation for high-frequency seismic ground motion simulation by subdividing the fault plane into subelements and summing their contribution at the observation point.

The semi-empirical methods have been developed for simulating earthquake ground motion due to rupture process [Midorikawa, 1993; Joshi, 2004 etc.] Such methods combine both empirical Green function technique and empirical relations based on recorded data.

The similarity relationships between the source parameters of the predicting large earthquake and small events are used. Usually it is used the scaling laws for source spectra obtained by Kanamori and Anderson (1975).

4. THE ACCURACY OF MODELING CALCULATION

Lot of input parameters used to predict strong ground motion based on source model. This permits to obtain the best agreement between synthetic and observed accelerogram at least for the particular source using selection of parameters values. Absents of the calculation accuracy estimations is main lack of modeling. Boore (2003, 2005) have estimated that obtained parameters of source and media it is possible to extrapolate not far than up to 100 km. In these articles the response spectra were calculated for the earthquakes with moment magnitudes $M = 4$ and $M = 7$. According to empirical data spectra logarithmic bandwidth is practically constant disregard to magnitude, faulting type, distance and ground condition. The standard deviation due to these factors and casual fluctuations is only 0.24 decimal logarithmic units. The calculated spectrum bandwidth for the $M = 4.0$ well correspond to empirical data, but one for earthquake $M = 7$ differs from mean empirical estimation by some standard deviations. It seems that such error is related to wrong scaling model. According to [Boore, 2003] 2 - 3 –times residuals of amplitudes shows relative good agreement. But such error is equal to error more than one seismic intensity unit. Modern semi-empirical equations to describe the acceleration attenuation have the error in near-field area equal to about 0.4 intensity unit. Empirical estimations of seismic intensity have the same standard deviation. The errors due to estimation of $\Delta\sigma$ are significant: according to [Boore, 2005] and [Boore, Boatwright, 1984] variations are more than 100%. Boore believes that the spreading function is constant in every distance intervals (<70 km, 70 - 130 km and > 130 km). This assumption is in contradiction with empirical strong motion data.

To obtain more precision results often a set of synthetic accelerograms are calculated, then mean values of motion parameters are estimated. Here origin the new problem – what is the obtained “mean” spectrum? From methodical point of view it is weight-envelop of single calculated spectra. Such a processing lead to overestimating of the frequency bandwidth and underestimating of the level. Therefore it is impossible to use this spectrum to calculate velocity spectrum, calculate predominant period of velocity. Error can reach 500% and more.

We have carried the comparison between the ground motion parameters estimation obtained by method of source modeling and empirical values. In the Table 3 are shown such results for weak and strong earthquakes taken from [Boore, 2005] and statistical values for strike-slip mechanism of earthquakes.

Table 3 Parameters of ground motion on rock at the distance of 10 km

	$M = 4$		$M = 7$	
	[Boore, 2005]	Statistical values	[Boore, 2005]	Statistical values
A, cm/s^2	41	85	346	633
T_0, s	0.07	0.06	0.8	0.38
d, s	0.24	0.24	8	3
S	0.82	0.55		0.55

The accelerations obtained by source modeling method half the empirical ones. Designed logarithmical bandwidth differs from empirical one for weak earthquake on standard deviation.

For the strong earthquake the related response spectrum is not available, but taking into account the Fourier acceleration spectra and scaling law used, the difference must be very large. The estimations of predominant periods and durations for the weak earthquake are practically the same. But for the strong earthquake these differences are more than 100%. Boore (2005) has calculated accelerations very close to fault (0.1 km) for earthquakes M = 5 - 5.9 and M = 6 - 6.9. In the first case he has obtained PGA = 340 cm/s^2 and for the second case 520 cm/s^2. The empirical data show that at the rupture surface the accelerations are constant and not depend on earthquake magnitude: PGA = 633 cm/s^2 for strike-slip faulting.

4.1. Predicting of Strong Ground Motions for Uttarakashi Earthquake, 1991, 20, October

To estimate accuracy of spectra calculations we use the data for Uttarakashi earthquake, India, 1991, obtained on 13 strong motion stations. Earthquake has parameters: magnitude M = 7.1, depth 19 km, faulting – thrust, distance 27 km, ground on station – alluvium. On the Figure 1 are shown normalized spectra with 5% damping: 1) the expected one, based on world-wide statistics (50% confidence level); 2) one for confidence level 67% for predominant period and 84% non-excided logarithmic frequency band; 3) “mean” one for 13 stations recorded this earthquake [Chandrasekaran, Das, 1991], and 4) - 5) ones calculated (two horizontal components) for the Bhatwari station using the modified Boore’s source model [Joshi et al., 1999; Joshi, 2004]. The parameters of ground motions are shown in the Table 4. In the modeling the site amplification are taken into consideration, in the statistical method – no.

From the Table 4 and Figure 1 one can obtain the following results. The response spectrum calculated using source model is larger in comparison with the real single spectra (about one standard deviation). The comparison of mean frequency bandwidth and bandwidth of “mean” spectra (Figure 1) shows that last is much wider than any particular synthetic spectra. Here the calculated and observed data are in relative good agreement because of the observed record is used. Nevertheless the differences of accelerations, frequency bandwidth are significant. The maximum on the period 0.64 sec is connected with ground amplification.

Table 4 Observed and calculated parameters of ground motion during the Uttarakashi earthquake, 1991 at the Bhatwari station

Values	Recorded	Statistics	Modeling
T_0, s	0.64	0.31	0.29 and 0.64
d, s	4.3	3.8	4.8
S		0.55	0.89

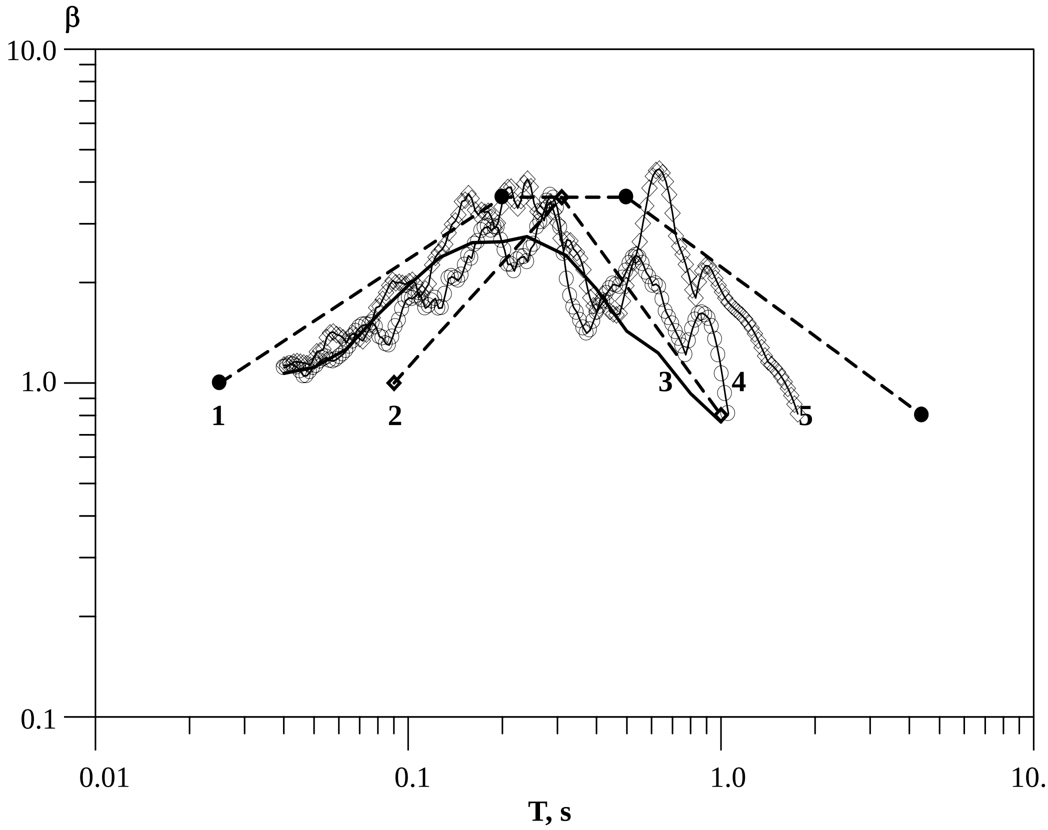

Figure 1 Response spectra modeled Uttarakashi earthquake, 1991, using different methods:
1 – confidence level 67% for predominant period and 84% non-excided logarithmic frequency band;
2 – expected (confidence level 50%); 3 – “mean” for 13 stations recorded this earthquake;
4 and 5 – two horizontal components obtained for the Bhatwari station using source model [Joshi, 2004].

5. CONCLUSIONS

It is necessary for seismic treatment assessments to develop the procedure to estimate accuracy of results obtained using source model method.

The main reasons of errors are:

1. Errors of the source model. Recently a lot of different models are developed. Every model has different suppositions. For example the supposition that all the energy is radiated from rupture surface. Spectra scaling law is very important also.

2. Errors of media model. For example for the earthquake M = 6 in range up to 70 km one can select at least two zones with very different amplitude attenuation, due to energy radiation and absorption by every element of media, influence of rupture surface (near this surface wave front is not spherical), dependence of attenuation decrement on level of velocity. The borders of zones depend on the earthquake magnitude. Therefore this factor rather is source features than media one.

3. To extrapolate ground motion parameters from far-field zone to near field one the media quality Q is used. But in techniques and seismology it is known that this parameter is strongly depends on the level of vibration.

4. Errors of the selected type of distance. For example, Boore determines the distance as $R = (D^2 + h^2)^{0.5}$, where D – shortest distance to vertical projection of rupture surface on the day surface. But it is known that the best

results gives the using the shortest distance to rupture surface.

5. The preliminary estimation gives the errors of all the ground motion parameters about 100%.

In the Report of Workshop USGS (1988) related to possibility of strong ground motion prediction using source models it is resumed that recently strong ground motion records permit to develop the source model not on the contrary. It is truth on our days.

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