Simulation of ground motion in the Moscow region using the empirical Green's function

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ABSTRACT

From historical times, the Moscow region is influenced by intermediate-depth strong earthquakes from the Vrancea seismic region, Romania. This influence is rather weak (intensity 4 of MSK-scale), but repeatable (several times per century); and it should be taken into account in earthquake-resistant design of high-rise constructions. Although the Vrancea source zone is located at a distance of 1400 km from Moscow, its specific characteristics: predominant source mechanisms, depth of events, rupture directivity, etc. result in rather weak attenuation of seismic radiation in the north-north-east direction, i.e. towards Moscow, which is proved by numerous publications.

The empirical Green's function method is widely used in evaluation of strong ground motion from known or expected earthquakes and displays its effectiveness. We applied it to calculate the synthetic accelerogram of the scenario earthquake of M_w=8.0 from the Vrancea region.

The initial data available were very poor. No accelerograms were recorded in Moscow. The disastrous earthquake of 1977, M_w=7.5 was recorded by the old-type analog system (sensor Kirnos) on photographic paper. These records, initially being the displacement, were carefully digitized. The only earthquake from the Vrancea region digitally recorded at the seismic station Moscow is the event of 2004, M_w=5.8.

Regarding this record as the empirical Green's function, ground motions were simulated for the known earthquakes of 1977 and 1986. The quality and validation of results were controlled by the comparison with the records of seismic station Obninsk (100 km from Moscow) that belongs to IRIS. In this case, we were able to use records of stronger earthquake (M_w=6.9, 1990) as an element event. To adjust these records to Moscow position, the special algorithm was developed based on the comparative analysis of different records obtained in Moscow and Obninsk respectively.

Special study was carried out on source scaling properties of the simulated events. Several publications stated the increase in stress-drop values for strong Vrancea earthquakes. But in our case the source event is also characterized by rather high stress-drop values, which allows the direct modeling of target events.

The results obtained indicate rather stable simulation of ground motion. The final evaluations are reliable enough and can be applied by engineers. The study is partly supported by the Russian Foundation for Basic Research, project No. 08-05-00598.

Key words: ground motion simulation, empirical Green's function, synthetic seismograms

PRESENTER'S BIOGRAPHY

Vera Bykova graduated from the Lomonosov Moscow State University, Faculty of Physics in 1985; PhD degree, in 1992. Since 1985 she works in the Institute of Physics of the Earth, Russian Academy of Sciences, now occupying the position of senior researcher. Recent activities are connected with the field seismological observations including the compilation of databases, study of site effects on seismic recordings in field conditions, local earthquake tomography, transfer functions of different instruments, and evaluation of seismic noise characteristics at various sites.

A First estimate of Site effect in the Indo-Gangetic Plains

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ABSTRACT

In India, the seismic source for great earthquakes exceeding M≥8.0 lies in the Himalayan belt. The Indo-Gangetic plains which run parallel to the Himalayan belt comprises of thick pile of alluvium of varying thickness from few hundred meters to about four kilometers. The major cities which are located in the Indo-Gangetic plains within 300-400 km from the Himalayan belt, for example, parts of Delhi, Lucknow, Kanpur, Allahabad, Dehradun, Patna and others are exposed to great seismic hazard. A network of 10 Digital Broadband Seismic stations has been installed across the Indo-Gangetic plains to study the crust-mantle structure in the region. Using two earthquakes which were recorded at the network and located in the Himalaya, we computed the site effect in the Indo Gangetic plains vis-a-vis seismic network operated by Wadia Institute of Himalayan Geology located on hard rock terrain in the Himalaya. Preliminary analysis clearly brings out the fact that site effects are larger in the Indo Gangetic plains due to the presence of thick pile of sediments. Using Empirical Green's Function approach the ground motion prediction for larger magnitude earthquakes in the vicinity of the epicenters of these two earthquakes is attempted.

Key words: Ground Motion prediction, Himalaya, Seismic Hazard, Indo-Gangetic plains, Green's Function

PRESENTER'S BIOGRAPHY

Dr.R.K.Chadha is presently working at the National Geophysical Research Institute, Hyderabad, India. He is engaged in the seismology research in the country for the last 25 years and published 52 research papers in the international and national journals. His interests are mainly in studying seismic hazard in the country in addition to triggered earthquakes and broadband seismology. He is presently, the Secretary General of the Asian Seismological Commission, a sub-commission of the IASPEI. He is also the President of the Natural Hazards Society.

Strong Ground Motion Prediction for the Stilfontein Earthquake, M_L5.3

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Different approaches have been developed to simulate strong ground motion. A method for modelling of strong ground motion should be able to simulate a source space time evolution and wave propagation from a fault to the receiver. A synthetic seismogram using a wave propagation model can be calculated; however only when the velocity structure is well known. Stochastic simulation, with an assumption about ray path attenuation could be an alternative option.

The fault geometry, heterogeneity of slip on the fault plane, and directivity can influence the ground motion in the far and near field. If the scenario earthquake is in the near field, a point source model is not suitable for ground motion prediction. Most often, a large fault is divided into subfaults and each subfault is considered as a small point source. The waveform of a small event is time delayed, scaled, and summed to simulate the ground motion of a large earthquake. The method presented here, simulates a subevent using random vibration theory. The earthquake source is represented as a set of point sources with a source time function. The source time function of the simulated earthquake is represented as a linear combination of the source time function of the subevents. This approach enables the inclusion of directivity into simulation the process.

The largest earthquake of magnitude 5.3 associated with deep gold mining was recorded near Stilfontein town, South Africa. The earthquake was located at a depth of 2 km on an ancient normal fault. Underground investigation revealed strong fragmentation of the fault. The earthquake was well recorded by underground mining networks. The individual pulses were resolved within the S-wave train. All pulses are assumed to be associated with the failure of patches of the source region. Temporary and space variation of the dynamic properties rupture was obtained. Those measurements lead to the construction of a model of seismic source as a composition of the asperities, with additional displacement outside the area of those asperities. The inversion result was used as input to model synthetic ground motion. Synthetic spectra of an earthquake of magnitude 5.3 were obtained by using a model of the extended source and, for comparison, the point source model. The synthetic seismogram and its spectra display significant differences for the different azimuths. Source complexity has a significant effect on near source earthquake ground motion. Rupture directivity and rupture heterogeneity have to be incorporated into seismic hazard assessment, which could be done through incorporation of those two parameters into ground motion prediction.

Seismic signature of subducting seamounts on the faulting process of the 2003 great Tokachi-Oki, Japan earthquake

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By analyzing broadband SH-wave seismograms from the Mw 8.3 September 25, 2003 Tokachi-Oki earthquake,we find that rupture occurred on a shallowly dipping fault and spread out in all directions from the hypocenter. The down-dip rupture speed is ~2.5-3 km/s, while the up-dip speed is much slower (~1 km/s). Used in conjunction with relocated aftershocks, we find that two along-strike barriers constrain the faulting extent of slip, creating a rupture area of ~165km x 140km. A high maximum slip of ~18 m is found in one region of the fault, with the average slip being ~3.3 m, giving an average stress drop of ~.75MPa. The barriers have high concentrations of large aftershocks around them. The locations and areas of the high slip regions agree well with that obtained from analysis of strong ground motion data (Nozu and Irikura, BSSA, 2008). The high slip regions resemble in size and shape the many seamounts about to subduct on the Pacific plate.

Stochastic self-similarity of envelopes of high-frequency teleseismic *P* waves: a hint at fractal organization of an earthquake rupture

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ABSTRACT

High-frequency (HF) seismic waves radiated by a large earthquake can be observed, with some distortion, either in the form of an accelerogram, or as teleseismic *P* waves. It is the latter case that is studied here. A wave train of teleseismic *P* waves looks like a segment of modulated noise, with its duration close to the duration of rupture: from tens to hundreds of seconds in the range M_w=7-9.5. Such signals look highly intermittent, with bursts and fadings; they rarely follow a primitive model of stationary random noise modulated by a smooth envelope function. One can try to use a stochastic approach in order to quantitatively describe this bursty behavior. Such a description may cast light on real complexity of rupture dynamics; it is also of vital importance for realistic evaluation of possible strong ground motions. Toward this end, variogram and spectral analyses are applied to time histories of *P*-wave instant power estimated over a few HF spectral bands. Eight M_w=7.6-9.2 earthquakes were examined, both from subduction and crustal-tectonic areas. For each event, 8-30 records were analyzed. Variograms and power spectra of time histories of instant power were determined simultaneously for eight non-overlapping HF bands, each with the same bandwidth of 0.7 Hz. All variograms look approximately linear in log-log scale, indicating self-similar correlation structure of the signal. The standard parameter to specify such a correlation structure is the Hurst exponent *H*. Its value that can be directly estimated from the slope of log-log variogram plot. All event-average values of *H* are in the limited range 0.71-0.80. Similarly, power spectra of the instant power signal look linear in log-log scale ($1/f^{\alpha}$ behavior), again indicating self-similarity. Event-average estimates of α are in the range 0.56-0.66. These estimates can be converted to *H* values in the even more narrow range of 0.78-0.83. Time-domain and frequency-domain estimates of *H* are consistent. The analysis of variance structure for *H* estimates has shown the following. Inter-record variance of *H* estimates is 0.062^2; inter-band variance is similar. Both these kinds of variation seem to be related to purely statistical fluctuations, and bear no physical meaning. In particular, there is no indication of frequency dependence of *H*. Inter-event variance, equal to $(0.015\text{-}0.03)^2$, is significant, it shows real differences between events. However, when compared to the entire reasonable range of *H*, between 0.5 and 1, the range of inter-event variations of *H* look rather narrow. On the basis of these results one can assume that the values of *H* around 0.75-0.8 are characteristic for HF signal envelopes of large earthquakes in general. The results suggest that the space-time organization of the earthquake rupture process has significant self-similar or fractal features; it is multi-scaled and significantly deviates from the brittle-crack model (with its one or two well-separated characteristic scales). No manifestation was found of characteristic subsource size that can be expected on the basis of most composite-crack fault models. From the viewpoint of applications, self-similarity of envelopes may provide a useful constraint for earthquake source models employed in the simulation of strong ground motions. The study was supported by the Russian Foundation for Basic Research through grant 07-05-00775.

Key words: earthquake, *P*-waves, high-frequency, self-similar, fractal, variogram

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Born 1945, Moscow, Russia. Candidate of Science: 1978; Doctor of Science: 1993. *Research field*: earthquake source models; strong ground motion analysis and simulation; randomly scattered seismic waves; and more. *Employment*: various institutions at Petropavlovsk-Kamchatsky, Russia (1967 to present); at UNAM, Mexico, in 1995-1996. *Results*: Proposed a semi-empirical scaling law of earthquake spectra with “humps” (lacking similarity) (1981) and “multiasperity fault model” to explain it (1988). Represented an extended fault as a non-coherent random source (1981), and derived realistic attenuation laws for acceleration spectra (1981) and macroseismic intensity (1999). Applied Monte-Carlo technique to model random anisotropic scattering of seismic waves (1987); proposed a model for self-similar properties of scattering (1996). Reconstructed size and duration parameters of earthquake sources from HF body wave instant power signals (1991, 1998, 2007). Revealed the non-Gaussian, heavy-tailed type of distribution for accelerogram amplitudes (1996). Estimated the vertical profile of turbidity of the lithosphere using back- and forward-scattered waves (1995, 1999). Found order clustering of a fractal kind in catalogs of volcanic eruptions for Kamchatka (2003) and world (2008).

Verification and Applicability of "Recipe" of Predicting Strong Ground Motions for Inland Crustal Earthquakes

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ABSTRACT

Slip heterogeneities inside rupture areas of large earthquakes have been found from the results of the waveform inversion using strong motion data. Destructive ground motions including short-period components are generated from such heterogeneities. Asperities are defined as areas with large slip based on slip distributions from the waveform inversion. We confirmed that the areas generating strong ground motions coincide with the asperities mentioned above. Then, we define a characterized source model with asperities in an entire rupture area for simulating strong ground motions. We found that ground motions from recent inland-crust earthquakes are well simulated using the characterized source model. Then we developed a "recipe" to construct the characterized source model for predicting strong ground motions.
This recipe gives source modeling for earthquakes caused to specific active faults obtained from geological, geo-morphological surveys and geophysical investigations and two kinds of the scaling relationships for the fault parameters. One is the conventional scaling relations such as rupture area versus seismic moment and fault slip versus seismic moment. The other is the new ones such as asperity area versus seismic moment and asperity slip versus seismic moment. Based on such scaling relationships, the source model for predicting strong ground motions is characterized by the outer, inner, and extra fault parameters. The outer fault parameters are to outline the overall pictures of the target earthquakes such as entire source area and seismic moment. The inner fault parameters are parameters characterizing stress heterogeneity inside the fault area. The extra fault parameters are considered to complete the source model such as the starting point and propagation pattern of the rupture.
The verification and applicability of the procedures for characterizing the earthquake sources for strong ground prediction are examined in comparison with the observed records and broad-band simulated motions for recent disastrous inland earthquakes.
We show a case of the 2007 Chuetsu-oki (Mw 6.6) as one of examples. This earthquake occurred very close to the Kasiwazaki-Kariwa Nuclear Power Plant. Ground motions from this earthquake are well simulated based on the characterized source model. We also examined the applicability of the recipe to other recent disastrous earthquakes such as the 2007 Noto-hanto earthquake, 2005 Fukuoka earthquake, and so on.
We find the "recipe" is useful for predicting design ground motions for earthquake safety designs as long as the source fault is specified through investigation of active folds and faults and the fault parameters are given considering regional characteristics.

Key words: strong motion prediction, recipe, characterized source model, asperity, active fault, 2007 Chuetsu-oki earthquake.

PRESENTER'S BIOGRAPHY

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Dynamic Rupture Modeling Considering Style-of-Faulting and Tectonic-Loading Dependent Stress and Strength Heterogeneity

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ABSTRACT

Shear failure during shallow earthquakes on pre-existing faults is governed by Coulomb friction, and hence the style of faulting and the tectonic loading history in compressional and extensional tectonics are important for determining the absolute value of frictional strength and the initial stress on the fault prior to rupture. For a fault system under confining pressure equivalent to the gravitational load, compressional tectonic loading accumulates shear stress on the fault while simultaneously increasing frictional strength due to increasing normal stress. In contrast, extensional tectonic loading results in a reduction of the shear strength due to decreasing normal stress. In this case, the resulting strength of the fault would not be able to maintain large shear stresses because the normal stress at shallow depth is limited to the gravitational loading.

To study the effects of these loading regimes on earthquake source dynamics, we develop suites of dynamic rupture models on thrust, normal and vertical strike-slip faults. For each class of models we combine stochastic irregularities in initial stress, compatible with seismological observations and findings from previous dynamic rupture simulations, with the external tectonic loading. Due to the nature of the fault systems described above, the normal stress is depth dependent, consequently the frictional strength (static and dynamic sliding strength) is also depth dependent. Our tectonic loading scheme generates increasing shear stress on the fault plane until a nucleation criterion is met. Assuming linear slip-weakening friction during fault rupture, we perform spontaneous dynamic rupture simulations to examine the rupture complexity and specific characteristics of these classes of models. Computing the associated near-field seismic wavefield radiated by these complex dynamic ruptures allows to re-examine the level and variability in ground-motion in the context of ground-motion prediction for seismic hazard analysis.

Simulation of Strong Ground Motions of Wenchuan earthquake by Stochastic Finite-fault Method

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ABSTRACT

Wenchuan earthquake (Ms=8.0, May 12, 2008, Sichuan, China) had caused great losses both in life and property. According to the theoretical study and accumulated practical experience, this paper synthesizes the accelerograms of Wenchuan strong earthquakes by Stochastic Finite-fault Method and their isolines are also obtained by PGA at each net point. It is known from our analysis results that (1) the main characters of this earthquake, i.e.,large affecting region, huge energy release, longer fault size, larger PGA and longer duration, could be reproduced reasonably again by our method; (2) the biggest PGA is not in the epicenter area (Wenchuan) but in Beichuan-Mao county; (3) The hanging wall effect, larger acceleration on hanging wall than that on foot wall, is also represented by our methods;(4) The PGA distribution is not symmetrical in different directions, larger PGA could appear in some special areas, which indicates the complexity of wave propagation and local site effect on ground motions.

This study will benefit to research of analyzing reason and degree of structural destruction caused by strong ground motions during this event, which will improve the stochastic finite-fault method comments, and also improve structural aseismic capability.

Key words: Wenchuan earthquake; accelerogram; stochastic finite-fault method.

PRESENTER'S BIOGRAPHY

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