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Preparatory Joint Working Group on Neo-Deterministic Seismic Hazard Assessment (pJWG NDSHA)

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More reliable physics in seismic hazard assessment (SHA) for disaster risk reduction (DRR)

(More reliable physics in SHA for DRR)

This issue

NDSHA-related session in the ASC 15th GA: Abstracts (I)

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The 15th General Assembly of the Asian Seismological Commission (ASC) is going to be held on November 3-7, 2024 (https://www.asc2024.org/). JWG proposed the session S15 'Neo-deterministic seismic hazard assessment (NDSHA): Progress and scientific debate', chaired by Antonella Peresan, Fabio Romanelli, Mohamed ElGabry, Guoxin Wang, and Yan Zhang. The focus of the session is on: a) The theoretical, computational, and application aspects of NDSHA, b) A discussion of related science and a comparison with other approaches, and c) Communication between NDSHA and engineering and emergency management communities for its application. **The deadline for abstract submission is July 30, 2024.**

Here, we attach the first part of the received abstracts for your reference. The presentations are mainly on the controlling earthquakes with time-dependent features. Contributions from African members of the JWG are obviously welcome.

M_{design} of the maximum credible earthquake (MCE) for scenario seismic hazard assessment: a comparative discussion

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In deterministic seismic hazard assessment (DSHA), the maximum credible earthquake (MCE), which was proposed some decades ago, plays an important role. The neo-deterministic seismic hazard assessment (NDSHA), that effectively accounts for the tensor nature of earthquake ground motions, formally described as the tensor product of the earthquake source functions and the Green's functions of the transmitting anelastic medium, and naturally supplies realistic time series, readily applicable to engineering analysis, not only rejuvenated the concept of MCE but also proposed the M_{design}. The M_{design} for the MCE combines the seismological concept of the uncertainty and predictability of earthquake magnitude and the engineering concept of safety factor and therefore supplies a quite practical and rational instrument towards the reduction of seismic disaster risk. The exploitation of the safety factor, the engineering concept exposed in the Eurocode 0 is one of the important bases. Considering the regional feature of the structural engineering design for seismic safety, we conduct a comparative analysis using the Eurocode and the Chinese code, respectively. The comparison indicates that for Chinese key engineering and lifeline systems, the safety factor consideration leads to a similar M_{design}. For any given area, once computed the first time, M_{design} must be adjusted only in case of being significantly exceeded within experimental error. Based on the Gutenberg-Richter frequency-magnitude scaling of major to great earthquakes, and the associated Zipf distribution, we discuss the scenario when M_{design} is exceeded and necessarily adjusted. It seems that if the GR scaling holds the M_{design} can naturally avoid the record-breaking case. The record-breaking case which needs the tuning of M_{design} may be related to the seismic 'dragon king' events which have been discussed in the physics of complexity since this century (EPJ 205 ST, 2012). Our discussion follows basically a comparative process: (a) comparison between the European code and the Chinese code, (b) comparison between engineering and seismological concepts, (c) comparison between earthquake science and physics of complexity, and (d) comparison between SHA endeavors and disaster risk reduction (DRR) endeavors. In such a way we hope to promote the fusion of at least some of these fields for the betterment of seismic resilience of the society.

Near-fault velocity pulses with implications for the maximum credible earthquake (MCE)

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The maximum credible earthquake (MCE) in deterministic seismic hazard assessment (DSHA) deals with the extreme case of earthquake hazards which, if neglected, may cause extraordinary destruction to structures. In such an extreme case, the near-fault region is the extreme of the extremes. As a distinct type of near-fault ground motion, it has been recognized in earthquake engineering for quite a long time that near-fault velocity pulses may cause severe damage to some structures in the near-fault region. Such near-fault velocity pulses, with characteristics of high amplitude, long period, and solitary-wave-like concentrated energy, is found to be related to the directivity effect and fling step effect, plus some other factors which are to be studied in detail. We investigate the strong ground motion records and associated destructions in several earthquake cases with the aid of numerical simulation. We discuss the near-fault velocity pulse associated with large earthquakes, with its implication for the MCE. Worth pointing is that the destruction seems beyond the scope of the presently well accepted, traditional DGA-intensity relation. The consideration of such special cases may contribute to the setting of the Mdesign for the MCE in the neo-deterministic seismic hazard assessment (NDSHA) which faces to key infrastructures and/or special targets, with more sophisticated tools to predict the seismic hazard. In fact, NDSHA effectively accounts for the tensor nature of earthquake ground motions, formally described as the tensor product of the earthquake source functions and the Green’s functions of the transmitting anelastic medium, naturally supplying realistic time series, readily applicable to engineering analysis.

Maximum credible broadband seismic motion synthesis for major engineering projects based on Green's function database

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Constructing the Green's function database based on actual seismic records mainly involves using the empirical Green's function method to obtain high-precision and high-probability acceleration waveforms at the target location and corresponding seismic motion characteristic parameters. Generally speaking, the smaller the magnitude of an earthquake, the more frequent it occurs, with over 100000 earthquakes of magnitude 3-5 occurring globally each year. The records of these small earthquakes contain the complexity factors of the real source rupture process, propagation medium, and shallow site response. Large earthquakes synthesized from small earthquake records also contain this complex information to a certain extent and can overcome the difficulty of calculating the theoretical Green's function. One of the most effective methods to simulate strong ground motion characteristics of large earthquakes is to use small earthquake records observed near the source area.

With the continuous improvement of China's earthquake monitoring capabilities and the establishment of China's earthquake early warning network, more and more earthquakes are being recorded. China has constructed a large number of major projects, establishing small area earthquake monitoring arrays near the sites of these key projects, accumulating small earthquake records with magnitudes ranging from M3.0 to M4.9, which can be used to estimate the strong ground motion characteristics of destructive scenario earthquakes or destructive historical earthquakes near the sites, thereby reproducing historical earthquakes or understanding the main strength characteristics of future earthquakes in advance, and assisting in the earthquake prevention and disaster reduction tasks of major projects. With the development of seismic signal extraction technology, the ability to extract effective seismic signals is constantly improving. The number of small earthquakes that can be used as the Green's function will increase exponentially as the lower limit of magnitude decreases.

The Green's function database for major engineering projects will have better application prospects, providing more representative seismic inputs with engineering response characteristics for seismic damage analysis of major engineering projects, and further assisting the long-term earthquake prevention and disaster reduction tasks in the local area.

Deterministic and Probabilistic Seismic Hazard Assessment for Cross Ayihai Fault Area Near Gonghe, Qinghai Province, China

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Based on the fault data and seismogenic area source data near Gonghe, Qinghai Province, deterministic and probabilistic seismic hazard analysis studies were conducted for areas cross Ayihai Fault. The research results indicate that in the deterministic seismic hazard analysis considering the maximum magnitude of the Ayihai fault as 7.5 and the maximum magnitude of other faults as 7.0, the maximum PGA in the cross fault area can reach about 0.48g; In the probabilistic seismic hazard analysis considering both fault model and seismogenic area sources, the maximum PGA in the cross Ayihai fault area is about 0.5g. However, the seismic hazard analysis results in the southern edge of the Qinghai Nanshan Fault and the surrounding areas of the Xiangridagou Fault are greater than the deterministic calculation results.

Post-seismic crustal internal deformation in a layered Earth model

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The present study introduces a novel method for computing post-seismic crustal internal deformation in a layered earth model. The surface dislocation Love number (DLN) calculated by the reciprocity theorem was implemented as the initial value. Furthermore, numerical integration of the value from the Earth's surface to the interior was undertaken to obtain the internal DLN. This method does not require a combination of the

general solution and particular solution for the calculation of internal deformation above the seismic source, thus avoiding the loss of precision. When the post-seismic deformation within a certain period is calculated, the particular solutions at the beginning and end of the considered period cancel each other. This simplifies the calculation of post-seismic internal deformation. The numerical results depict that as the degrees increase, the post-seismic DLN reaches stability in a shorter interval of time. Thus, for improved efficiency of the post-seismic internal deformation calculation, the post-seismic DLNs should be calculated within 2000 degree and integrated with the co-seismic results. As an application, the post-seismic Coulomb failure stress changes (ΔCFS) induced by the 2011 Tohoku-Oki earthquake in the near field around the Japanese archipelagos and two major faults in Northeast China were simulated. The results exhibit that the ΔCFS values in the near field agree well with those simulated by the method in a half-space layered earth model, thus verifying the present method. The co-seismic ΔCFS on the Mishan-Dunhua fault in Northeast China, as an example, is only 0.094-0.668 KPa. However, the ΔCFS caused by the viscoelastic relaxation of the mantle within 5 years following the 2011 Tohoku-Oki event on the same fault exceeds the co-seismic results. Therefore, the cumulative effect of the viscoelastic relaxation of the mantle is deserving of attention.

Significance of accurate selection of the seismogenic faults from the earthquake focal mechanisms for stress field reconstruction

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The focal mechanism of earthquakes provides a critical insight into the stress state of the Earth's crust. Stress inversion based on focal mechanisms requires accurate identification of the seismogenic fault from the two nodal planes for each focal mechanism and then determination of the stress tensor by fitting the slip direction of the seismogenic faults. Currently, there are two dominant strategies for identifying the fault plane in different stress inversion methods. One strategy is to select the nodal plane with the smallest difference between the slip direction and the shear stress direction. The other strategy is to select the nodal plane with higher instability based on fault stability considerations. However, existing studies have shown that neither strategy can guarantee the accurate identification of seismogenic faults from all focal mechanisms. Therefore, the extent to which the stress result deviates from the true stress due to incorrect fault plane selection remains an important issue that warrants further investigation. If the accuracy of the stress inversion is slightly affected by the precision of the fault plane selection, then the process of selecting seismogenic fault planes from the focal mechanisms can be neglected. Conversely, if it has a significant influence, then the issue of precise fault plane selection must be addressed. This is an important issue that has not been studied thoroughly. The present study investigates this issue through synthetic experiments. The main conclusion is that accurate selection of seismogenic faults from focal mechanisms is essential for improving the accuracy of stress tensor inversion. The accuracy of the fault plane selection affects not only the recovery of the stress direction, but also the recovery of the relative magnitude of the principal stresses (R). The magnitude of this influence is closely correlated with the R value of the actual stress state. When

the actual stress R value is in the intermediate range, accurate fault plane selection enables accurate reconstruction of the R value. When the actual stress R value is small, accurate fault plane selection helps to accurately reconstruct the stress direction. Therefore, accurate selection of fault planes from focal mechanisms ensures accurate reconstruction of stress direction and R value under different background stress conditions. This is of great importance for a reasonable interpretation of tectonic movements based on the reconstructed stress state.

Preliminary Analysis of the Megacity Earthquake Risk in the Mainland of China

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In recent years, more and more attention has been paid to disaster prevention in urban underground spaces. With the continuous growth of urban construction scale and population, the potential risk of city earthquakes is also a worthy concern. The Ministry of Housing and Urban-Rural Development recently released the 2022 Statistical Annual Report on urban construction. According to the report, ten cities in mainland China have an urban population of more than 10 million, and 13 have an urban population of more than 5 million. The cities with a population of more than 10 million, named megacity, are Shanghai, Beijing, Shenzhen, Chongqing, Guangzhou, Tianjin, Dongguan, Wuhan, and Hangzhou. The urban population of Shanghai is more than 20 million, about 25 million. Generally, to predict the potential maximum magnitude of the earthquake in a city, we should take advantage of the regional seismicity, and we can also assess the risk of city earthquakes combined with strong ground motion and earthquake intensity simulation preliminarily. Since 1900, there are two megacities, which are Chongqing and Tianjin, have suffered city earthquakes with a magnitude above 5, and the largest ones are the Chongqing Jiangbei M 5.3 earthquake on November 20, 1989, and Tianjin Ninghe M 6.9 earthquake on November 15, 1976, respectively. For Shenzhen, Guangzhou, Dongguan, and Wuhan, there has been no earthquake with a magnitude above 3 since 1970. Only one earthquake, the Shanghai Qingpu M 3.0 earthquake on February 17, 1991, occurred in the urban area of Shanghai since 1970. Also, one earthquake, the Linan M 4.2 earthquake on April 12, 2017, occurred in the urban area of Hangzhou since 1970. The seismic activity appears to be more active in the urban area of Beijing. Since 1970, more than 30 earthquakes with a magnitude above 3 have occurred in the urban area of Beijing, including 9 earthquakes with a magnitude above 4, the largest city earthquakes are the Huairou M 4.5 earthquake on March 25, 1972, and Huairou M 4.5 earthquake on December 10, 1982, respectively. For the megacities, once a moderate city earthquake occurs, it is a very challenging task to make a rapid assessment of the earthquake intensity. It is also necessary to consider other potential city disaster risks associated with the city earthquake, such as fire, trampling, and damage to urban rail transit lines, comprehensively.

The forecasting efficiency under different selected regions by Pattern Informatics (PI) Method and seismic potential estimation in the North-South Seismic Zone

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PI method is a method of statistical physics to study seismic activity patterns. It creates a time-dependent state vector of the system representing seismic activity in Hilbert space, where the unit vector varies with time and identifies characteristic patterns of small earthquakes shifting from one location to another with time before a large earthquake. After learning each pattern, it identifies possible patterns of seismic activity at a certain time and gives the probability of occurrence of strong earthquakes. The PI method obtains the seismicity probability by analyzing the rise and fall of seismicity and its calculation process involves the normalization of seismicity in the whole study area. Therefore, different seismicity could affect the forecast of PI.

In 2022, four earthquakes with M_S≥6.0 including the Menyuan M_S6.9 and Luding M_S6.8 earthquakes occurred in the North South Seismic Zone (NSSZ), which demonstrated high and strong seismicity. In order to analyze the pattern of small seismic activity before strong earthquakes and to assess the seismic hazard potential of the region, and improve the forecasting efficiency of PI method for strong earthquakes in the NSSZ. We create different regional divisions according to the seismic activity intensity and geological tectonic characteristics of each region in the NSSZ. And carry out retrospective studies using the recent 5-year M_S≥6.0 earthquakes in the region as the seismic examples and the seismic forecast effectiveness of PI hotspot map by Receiver Operating Characteristic(ROC) test.

The study shows the following. 1) PI forecasting has higher forecasting efficiency in the selected study region where the difference of seismicity in any place of the region is smaller.
2) In areas with smaller differences of seismicity, the activity pattern of small earthquakes prior to the Men yuan M_S6.9 and Luding M_S6.8 earthquakes can be obtained by analyzing the spatio-temporal evolution process of the PI hotspot map. 3)The hotspot evolution in and around the southern Tazang fault in the study area is similar to that prior to the strong earthquakes, which suggests the possible seismic hazard in the future.

Communicating with ChatGPT as a viable alternative to communicating with the public: an experiment on Neo-deterministic Seismic Hazard Assessment (NDSHA)

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ChatGPT is a general pre-trained AI tool, learnt from and trained by a variety of publications both for academic communication and for education and outreach. Interacting with ChatGPT about certain scientific topics may resemble the interaction with the public in certain ways. To some extent it may mimic a sociological investigation. Whether Chatting with ChatGPT may obtain at least some meaningful sociological conclusions is one of the interesting problems deserving some experiments. Such an experiment with a case example is provided by the neo-deterministic seismic hazard assessment (NDSHA), which has been the subject of several publications debating its fundamental science and practical applications. This seems to be significant for the advancement of NDSHA and for the general public's comprehension of seismic hazards.

On the ‘human side’, the communication is based on professional knowledge, the participants having used NDSHA for a considerable amount of time. We communicate with ChatGPT on some key issues related to NDSHA and other related SHA approaches, including the maximum credible earthquake (MCE), the probabilities, the safety factor, the aseismic design, the seismic zonation, and the building code, among others. The knowledge and ‘insights’ of ChatGPT reflected in the communication represents the academic impact of the basic studies on NDSHA, while the misunderstandings of ChatGPT may be the result of lack of education and outreach. Comparison between the experiment with ChatGPT and that with QuakeGPT, a Chinese-based seismology-oriented GPT, shows some intriguing characteristics that require further future investigation.

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