Eastern Canadian experience with Mmax, the largest considered earthquake for seismic hazard calculations

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ABSTRACT

Probabilistic seismic hazard is computed by integration over a range of magnitudes, from Mmin, the minimum considered event, to Mmax (sometimes termed "Mx"), the largest considered. Mmax cannot be less than the largest observed event, but otherwise there are few universally-agreed rules. Canadian practice for the 4th Generation seismic hazard model (Adams and Halchuk, 2003, http://earthquakescanada.nrcan.gc.ca/hazard/OF4459/index_e.php) was strongly influenced by three large earthquakes that occurred in the decade following the completion of the 3rd Generation - Miramichi Mw~5.9, Saguenay Mw5.9, and Nahanni Ms6.9. Miramichi equalled the local Mmax used in the 3rd Generation, and Saguenay and Nahanni exceeded it by nearly 1 magnitude unit. Mmax for the 4th Generation was therefore chosen based on continent-scale and global analogs and leaned heavily on methods similar to the early 1990's EPRI study of stable continental regions. These choices were tempered by geophysical constraints (e.g. thin seismogenic crust) in a few regions. The smallest Mmax were taken to be the largest events from the most stable cores of the continents (7.0 +/-0.2), though this value should probably be revised upwards in the light of recent paleoseismic work from Australia. For the eastern Atlantic (Mesozoic) margin 7.5 (+0.5, -0.2) was used, and for the embedded (Paleozoic) rifted margin 7.5 (+0.2, -0.3) was used, based on each case on the presence of extensive fault systems. Recent geodetic (GPS) methods place uncertain upper limits on Mmax of 7.8 (+0.7, -0.6) for the Paleozoic rifted margin, but may provide additional constraints as longer time series are evaluated. Although occurrences of earthquakes approaching Mmax are rare, they can have a significant influence on seismic hazard, particularly at lower probabilities.

Key words: seismic hazard, Mmax

PRESENTER'S BIOGRAPHY

John Adams has nearly 30 years experience in seismicity, seismotectonics and seismic hazards in Canada. He is responsible for the Canadian national seismic hazard maps and participates in writing standards relating to seismic-resistant design.

GEMS: a Global Earthquake Monitoring System for stress-forecasting all damaging earthquakes worldwide

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ABSTRACT

Strange as it may seem, we understand the distribution of matter in the interior of the sun far better than we understand the interior of the earth. (Feynman, 1995)

The New Geophysics of a crack-critical Earth demonstrates that earthquakes can be stress-forecast by using bore-hole Stress-Monitoring Sites (SMSs) to monitor stress-accumulation in the rock mass at substantial distances from the impending epicentre. The prototype SMS in Iceland indicated that the sensitivity of rocks to increases of stress was such that a single SMS would recognise stress-accumulation accumulation before all $M \geq 5$ earthquakes within 400 km of the SMS. Since $M = 5$ can be taken as the lower limit of damaging earthquakes, this suggests that a Global Earthquake Monitoring System (GEMS) of a worldwide network of SMSs would stress-forecast all damaging earthquakes worldwide.

Recent advances demonstrate that SMSs can be controlled and recorded both onshore and offshore via Internet technology. The proposed GEMS network would have ~1500 SMSs (each consisting of three 1km-to-1.5km-deep boreholes) in a 400km grid in seismic areas and a 1000km grid elsewhere, both onshore and offshore.

GEMS would provide substantial benefits:

1) Data to stress-forecast of times and magnitudes of all damaging earthquakes worldwide with magnitudes greater or equal to M 5 (and many smaller events).
2) Facilities to monitor the effects of massive fluid-injection operations to optimise stress release to mitigate earthquake hazards threatening cities or other vulnerable locations.
3) Data for a stress-forecasting service, analogous to weather forecasting (another critical-system), to provide longer-term estimates of earthquake occurrence and hazard, as well as Earth evolution.
4) A network of deep boreholes for passive monitoring of broadband seismics, gravity, resistivity, magnetism, etc., in exceptionally-quiet environments for time-lapse monitoring of the dynamics of Earth evolution.
5) A new controlled-source tool for monitoring the (previously inaccessible/unknowable) evolution of the crack-critical Earth to stimulate geoscience at the beginning of the 21st century.

GEMS would be expensive but would provide for the first time data for examining the detailed evolution of the interior of the Earth (the Feynman anomaly) which is currently not possible. GEMS would provide a wholly new source of data giving unique information about the interior of the Earth. Papers presenting these ideas are available at <www.geos.ed.ac.uk/homes/scrampin/opinion>.

Key words: Forecasting all damaging earthquakes, Global Earthquake Monitoring System (GEMS), shear-wave splitting, Stress-Monitoring Sites (SMSs), the New Geophysics.

PRESENTER'S BIOGRAPHY

Stuart Crampin: PhD, ScD, FRAS, FRSE; Conrad Schlumberger Award (EAGE); Virgil Kauffman Gold Medal (SEG); highly cited <http://www.isihighlycited.com/>; h-index 36.

Crampin pioneered theory, observation, computation, interpretation of seismic anisotropy in 260$^+$ papers.

Crampin founded biennial International Workshops on Seismic Anisotropy (14IWSA will be in Perth, Australia).

Crampin founded Edinburgh Anisotropy Project (EAP) at BGS for processing multi-component seismograms. EAP still continues with ~20 oil company sponsors.

Crampin developed anisotropic poro-elasticity (APE) model of fluid-saturated crack deformation. APE led to the successful calculation (prediction) of oil production operations, and successful prediction of time, magnitude, and fault-break of M=5 earthquake.

Crampin developed prototype Stress-Monitoring Site (SMS) between 500m-deep boreholes which recorded spectacular sensitivity to remote minor seismic activity confirming science/technology/sensitivity.

Crampin is currently promoting the concept of crack-critical crust, where *in situ* cracks are so closely-spaced they are critical-systems. Consequently, low-level deformation can be monitored with shear-wave splitting, modelled/predicted with APE, and in appropriate circumstances, future behaviour controlled by feedback.

Stress-Monitoring Sites offer ways of mitigating earthquake hazard

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ABSTRACT

In situ rock is so weak to shear stress that the stress-accumulation before large earthquakes necessarily takes place over very large volumes of rock surrounding the impending source zone. If stress-accumulation, recognised at Stress-Monitoring Sites (SMSs) or above small earthquakes, appeared to be threatening a large city or other vulnerable location, in principle, the accumulating stress can be diminished almost anywhere within the larger stressed volume, by inducing small earthquakes so that the potential for a city-threatening earthquakes is reduced. The most direct way to release stress is fluid-injection by hydraulic pumping operations in less-vulnerable locations within 200 to 500 km, say, of the threatened location. Such hydraulic-fracturing is a routine oil-company operation, and injection should be sited in areas of low population density and low infrastructure in mountains, or deserts, or even offshore if suitable allowance can be made for tsunamis. Note that excited earthquakes are expected to be comparatively small.

Excitation of small earthquakes by fluid-injection was demonstrated at Rangely, Colorado, in 1976, and by numerous oil production procedures elsewhere, but has not, to our knowledge, been specifically used to mitigate the effects of impending large earthquakes. One of the major disadvantages in the past has been that such operations were largely uncontrollable and might excite the very event they are designed to prevent. Two developments have changed this perception: (1) The New Geophysics suggests that stress-accumulation before a large earthquake occurs over such a large volume that stress release by small earthquake excitation could be at substantial distances from the vulnerable location; and (2) The effects of changes in stress caused by fluid-injection can be directly monitored by SMSs and effects optimised.

This is, however, an untested procedure and the detailed effects are currently not known. The great advantage of SMS monitoring would be that the effects of such fluid-injection can be monitored and results optimised. The intention would be to release stress by exciting small earthquakes in areas, remote from major fault zones and major cities where earthquakes would be less destructive, but within the larger stressed volume.

Such hydraulic injection operations would need to be massive, extensive, and costly. However, the 1995 Kobe earthquake has been estimated as costing 250 billion $U.S. If accumulation of stress was recognised by a SMS, a premium of 0.1% would provide 250 million $US for substantial hydraulic fracturing operations if a city such as Kobe was threatened by an impending large earthquake. This would not be a blind investment. A SMS would allow the effects to be monitored and the stress release optimised. If hydraulic fracturing at one location was not proving effective for the release of stress, hydraulic pumping could be relocated within the stressed volume until an effective relaxation regime was located. This suggests that, for the first time, it is possible to understand, monitor, and control the effects of earth deformation and mitigate earthquake hazard. Papers presenting these ideas are available at <www.geos.ed.ac.uk/homes/scrampin/opinion>.

Key words: Hydraulic pumping, mitigating earthquake hazard, shear-wave splitting, Stress-Monitoring Sites (SMSs), the New Geophysics.

PRESENTER'S BIOGRAPHY

Stuart Crampin: PhD, ScD, FRAS, FRSE; Conrad Schlumberger Award (EAGE); Virgil Kauffman Gold Medal (SEG); highly cited <http://www.isihighlycited.com/>; h-index 36.

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A hazard-purpose seismicity catalogue for Western Iberia

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ABSTRACT

Due to its particular tectonic and geological setting – near the Eurasian-African plate boundary and weakened by aborted Mesozoic rifting -- Western Iberia is affected by both interplate earthquakes (offshore) and intraplate earthquakes. Proposed magnitudes for historical earthquakes reach **M**8.7 and **M**7.1 for interplate and intraplate seismicity respectively. Paleoseismological studies in northwestern Portugal indicate that, during the Holocene, the magnitudes of intraplate earthquakes reached the range **M**7.1-7.3.

Despite the importance of parametric data for pure and applied hazard research, currently there is no updated homogeneous-magnitude earthquake catalogue for Western Iberia. In the 1980's a considerable number of studies were performed in Portugal with the aim of recovering earthquake information from historical sources. This data was introduced in subsequent earthquake catalogues, but no modern quantitative methods or systematic procedure were applied to retrieve earthquake parameters.

In this study we present a moment-magnitude earthquake catalog for Western Iberia, based on previous historical studies and updated instrumental catalogs. Different magnitude scales were converted to seismic moment (M_0) through empirical relationships, and then to moment magnitude.

We use the catalog of Oliveira (1986), a detailed review on earthquakes that affected Portugal, as the basis for pre-instrumental seismicity. The events with epicentral location and macroseismic assessment rated as "good" or "medium" and MMI intensity VI or above were selected. This data-set was complemented with the events on the catalog of Instituto Geografico Nacional, Madrid (IGN, 2002) for which an isoseismal map was available. Around 85% of pre-instrumental events were not selected because they didn't meet the required standards. The M_0 estimate was performed with an empirical model using isoseismal areas, or, when isoseismal map was not available, through a maximum intensity model. For the November 1st, 1755 "Lisbon Earthquake" and the April 23, 1909 Benavente earthquake, we used values proposed by recently published work.

We use the IGN catalog for the period 1990–2007 as the basis for the instrumental period. This institution routinely calculates magnitudes using the maximum amplitude of the *Lg* wave calibrated with the body-wave magnitudes m_b given by the National Earthquake Information Service of U.S. Geological Survey. Whenever available (usually for larger-magnitude events) we preferred teleseismic magnitudes and **M** provided by the International Seismological Centre. We then used empirical relationships to retrieve M_0 from instrumental magnitudes.

The errors associated with moment magnitude estimates from isoseismal areas range from 0.30 to 0.40 units of **M**, for the analyzed earthquakes. These errors increase to 0.50–0.52 units of **M** when moment magnitude was calculated from maximum intensity. For instrumental magnitudes, the associated errors are in the range 0.10 to 0.30 units of **M**.

The catalog developed in the present work is complete, according to the method of Stepp (1972), since the following years: for interplate events with 6.9M<,7.1, 1531; with 5.8<M<6.8, 1858; with 3.8<M<5.7, 1925; for intraplate events with 4.6<M<6.2, 1953; with 3.5<M<3.9, 1963; with 3.3<M<3.4, 1987. In our view this catalogue fulfills the specific requirements of seismic hazard analysis, and can be useful in a variety of academic and applied hazard assessment studies.

Key words: seismicity; catalogue; seismic hazard

PRESENTER'S BIOGRAPHY

Dr Joao Fonseca graduated in Physics at the University of Lisbon, Portugal, in 1982, and obtained a Ph.D. in Geophysics at the University of Durham, UK, in 1990. Since 1992 he is a lecturer of Geophysics at the Instituto Superior Tecnico (IST) in Lisbon. He is currently a researcher at the Earthquake Engineering and Seismology Group of ICIST, a research unit of IST. Major research interests are seismic hazard assessment, volcanic risk mitigation and seismic instrumentation. Past and current research projects coordinated by Dr Fonseca investigated the active tectonics of the Lower Tagus Valley region near Lisbon, the intraplate seismicity of the same region, and the eruptive mechanism and volcanic seismicity of Fogo volcano, in the Cape Verde islands. Currently, Dr Fonseca is participating in FP7 projects MIAVITA (volcanic risk, coord. BRGM, Paris) and SHARE (seismic hazard assessment, coord. ETHZ). A topic od particular interest is the use of VSAT transmission of geophysical data in Africa.

Seismic microzonation and earthquake hazard scenarios in the Vega Baja region, SE Spain

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ABSTRACT

The Vega Baja region, located in the Lower Segura River Basin, is one of the Neogene-Quaternary depressions developed in the Betic Cordillera, SE of the Iberian Peninsula. The sedimentary fill is post-orogenic and its youngest materials, in general, are cohessionless or very soft silts and clays, mainly in the central part of the basin. Earthquake activity in the region is moderate at present, although the historical record contains references to several damaging events. The strongest earthquake occurred in 1829 and it is known as the Torrevieja earthquake, with a maximum EMS-98 intensity of IX-X. Both the very recent rapid growth of urban developments together with the increase of population in the area has greatly increased seismic risk. Geological, geotechnical and geophysical geo-referenced data, compiled for the area, have been harmonized in a common relational database fully compatible with GIS tools. A geological-geotechnical model of the region has been developed, based on this comprehensive geo-database, and further applied in site response and liquefaction potential analysis. Soil effects were evaluated by using empirical approaches, based on ambient noise records, and 1-D numerical methods. In general, the spatial distribution of the soil's fundamental frequencies allows defining three areas corresponding to specific soil characteristics. Ground motions, compatible with hazard-consistent scenarios at different probability levels, were used in combination with estimated soil effects, to generate a set of representative earthquake hazard scenarios in the Vega Baja. Earthquake hazard scenario results are shown by several zonation and microzonation maps at different levels of detail, suitable for their application in risk mitigation and emergency planning.

Key words: seismic hazard, earthquake scenarios, microzonation, Spain

PRESENTER'S BIOGRAPHY

M. Garcia-Fernandez is senior researcher at the Department of Volcanology and Geophysics of the MNCN-CSIC in Spain. He is working on Earthquake and Engineering Seismology, leading and co-leading different projects and initiatives, mainly focusing in the Mediterranean and Latin America regions.

Network analytical GIS for seismic hazard research

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ABSTRACT

The goal of the paper is to outline the functionality of network analytical GIS GeoProcessor 2.0 and GeoTime II. These GISs are aimed to solve two types of problems: (1) cartographic measurements, browsing through multidisciplinary geographic information and estimation of relationships between its components and (2) discovery of dependencies in geographic information, forecasting, detection and recognition of specific stationary and dynamical properties of the environment under study.

Both GISs support on-the-run integration and co-processing of the vector and grid-based data, distributed both on network servers and on a user's PC. Operations are supported by interactive visualization. Close interaction of the methods for analytical and visual research provides a basis for geoinformation simulation, which essentially simplifies understanding of the material under research and as a result enhances a decision-making efficiency. Both GISs are written on Java 1.6, thus providing platform independency and ability to run programs within any modern browser.

Network GIS GeoProcessor (http://www.geo.iitp.ru/app.php?link=gis:geoproc2) is targeted to perform analysis of spatial geographic information as well as to solve problems of spatial forecasting. The field of application comprises spatial-data analysis, geological environment research and decision-making support in such problems as seismic hazard assessment and environmental zonation. Analytical abilities of GIS are supplemented by visual research methods, vector and grid-based data calculations, operations of spatial forecasting and pattern recognition, etc. Considering examples of earthquake damage assessment, seismic hazard analysis, geophysical properties forecasting, GeoProcessor 2.0 proved to be an effective tool for fundamental and applied problem investigation.

GIS GeoTime II (http://www.geo.iitp.ru/geotime/index.htm) is intended for spatio-temporal process analysis and simulation. The field of application comprises seismic hazard, earthquake precursor analysis etc. The system consists of the kernel and a set of user-defined plug-ins that make the system capable to solve the problems in the specific areas of study. The animated visualization facilities of GIS provide visual exploration of 3D raster fields and 4D event catalogues as well. The system possesses a wide range of advanced analytical functions. Along with common vector and 3D grid-based calculations there are a number of additional plug-ins designed for computation of spatio-temporal fields of seismic characteristics. They comprise plug-in for minimal representative magnitude field estimation (M_{min}), b-value, seismic activity, RTL, plug-in for detection and significance estimation of spatio-temporal earthquake precursors, plug-in for temporal analysis of seismic event sequencees and plug-in for clusterization in seismic flow. Examples of applications manifest that GeoTime II is an effective tool for geodynamic research and seismic hazard analysis.

Both GISs were supplied with geoinformation resources for the regions: Central Europe, North Caucasus, Kamchatka, volcano Merapi, former USSR, East European platform, Central Russia, Western Siberia, China, North India and Central Asia. GISs and the resources are available in open access. The regional resources are based on digital data provided by IPE RAS, GC RAS, IGEM RAS, IDG RAS, Russian Aerospace Agency, Kazakhstan Institute of Seismology, Institute of Rock Structure and Mechanics, AS Czech republic, Institute of Earthquake Science of China EA, GFZ (Germany), University of Vienna, Wadia Institute of Himalayan Geology.

This work was supported in part by the Program of Presidium of RAS "Fundamentals of scientific distributed data-processing environment based on GRID technology", the section "Electronic Earth", and by the RFBR projects no. 06-07-89139, 07-07-12019.

Key words: network GIS, geoinformation resources, seismic hazard, earthquake precursors.

PRESENTER'S BIOGRAPHY

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EDUCATION:

M.Sc. in Automatic control, South Ural State University, 1960, Cheliabinsk, Russia.

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Dr. Sc in System analysis, control, and data processing & Geophysics and geophysical methods of deposit exploration, IITP RAS in 2001.

POSITION HELD:

IITP RAS, scientist, leading scientist, head of section for Geoinformaion Technology and Systems.

SCIENTIFIC CONTRIBUTION:

(1) Developed and implemented methods in pattern recognition and forecasting. (2) Developed and implemented fundamentals of spatial and spatio-temporal forecasting in geoinformatics. (3) Developed desktop GIS GEO 2.5, GeoTime, GeoRisk, and Web-GISs GeoProcessor, COMPASS, GeoTime II. (4) Developed problem domain GIS-applications for forecasting $M_{\max}$ expected earthquakes, earthquake prediction research, seismic risk assessment, environmental zonation, and mineral, oil and gas exploration.

Century-long recurrence times for surface ruptures of the San Andreas fault in California (USA): Insights on earthquake potential from paleoseismology and recent large earthquakes

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ABSTRACT

The San Andreas fault (SAF) represents a major source of seismic hazard and risk to millions of California residents. According to a recent (2008) statewide Uniform California Earthquake Rupture Forecast (UCERF), the 30-year probability of a M $\geq$ 6.7 earthquake in California is > 99%, with the SAF accounting for most of the hazard. The probability of a M $\geq$ 6.7 earthquake on the southern half of the SAF is reported to be 59%. Of greatest concern is the potential for a large earthquake. According to UCERF, the probability of a M 8 earthquake is 4% within the next 30-years. In California, forecasts of the largest earthquakes are anchored with paleoseismic data because the historic record of seismicity is relatively short. The two largest earthquakes in California's history both occurred on the San Andreas fault in 1906 and 1857 A.D. in northern and southern California, respectively. Recent attention has focused on the southernmost section of the SAF as a likely source of the next large earthquake as it appears that this section of the southern SAF has not ruptured for over 300 years. Paleoseismic investigations in the Coachella Valley indicate that the last rupture of the southern SAF occurred in approximately 1680 A.D. and the average recurrence time is approximately 200 years. Recent paleoseismic research results at other sites along the SAF also show that the current open time interval since the last rupture is approaching or exceeds the average recurrence interval for surface ruptures. At Arano Flat in northern California, the SAF last ruptured in the great 1906 San Francisco earthquake, and the reported average interval between the last 9 earthquakes is 106 years. At several paleoseismic sites on the southern SAF, including Wrightwood, Pallett Creek, Frazier Mountain and Bidart Fan, reported average intervals are 100 - 130 years, and the time since the last rupture is >150 years. In the Carrizo Plain the SAF has ruptured six times since ~ A.D. 1250, with the most recent earthquake in A.D. 1857. When combined with the apparent seismic gap in the Coachella Valley, it appears that the entire southern half of the SAF could rupture in a large magnitude earthquake or cascade of earthquakes similar to the historic westward propagating sequence on the North Anatolian fault in Turkey. A similar sequence of earthquakes ruptured most of the SAF through southern, central and northern California in A.D. 1812, 1857 and 1906. The occurrence of similar rupture sequences in the past would be difficult to identify in the paleoseismic record because uncertainty in dates of paleoearthquakes is too large to identify synchronous rupture. However, the average time between ruptures at multiple locations along the fault suggests that cascading earthquakes or rupture sequences should be considered in assessing seismic hazard.

Key words: San Andreas fault, paleoseismology, surface rupture potential, earthquake recurrence, seismic hazard

PRESENTER'S BIOGRAPHY

Lisa Grant Ludwig attended Stanford University as an undergraduate and then earned her Ph.D. and two M.S. degrees from Caltech. She is currently an Associate Professor in the Program in Public Health at UC Irvine, and an Associate Director of the California Institute for Hazards Research of the University of California. She is also serves on the Board of Directors of the Southern California Earthquake Center, and conducts research on active faults and seismic hazards, with a focus on California.

Time independent seismic hazard in Iran

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ABSTRACT

The seismic hazard analysis can provide long term probabilities of seismic event occurrence of specific size in a given time window. Different methods have been proposed for assessing seismic hazard. In this study we have used the Bayesian probability theory for earthquake occurrence to obtain the time independent probability of exceeding of a certain earthquake at a certain time window in different cities of Iran. The selected cities are those which have already been destroyed by large historic or recent earthquakes. The Bayesian probability estimation seems to have efficiencies that make it suitable for calculating different parameters of seismicity. The classical approach to statistical estimation is based on the concept that the unknown parameter is a constant and all we know about the unknown parameter is included in the random samples selected from the population. While the Bayesian approach to the estimation considers the unknown parameter as a random variable with some prior probability distribution. The method is able to combine prior information on seismicity while at the same time including statistical uncertainty associated with the estimation of the parameters used to quantify seismicity, in addition to the probabilistic uncertainties associated with the inherent randomness of earthquake occurrence. So the time independent Bayesian approach which yields the probability that a certain cut-off magnitude will be exceeded at certain time intervals is examined for Iran.

Keywords: Iran, time-independent, seismic hazard, probability distribution, bayesian estimation.

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M_{max} in Iran

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ABSTRACT

Iran is located between regional moving plates within the Alpine-Himalayan mountain belts. The geographical location of the country is the key to its present active tectonics and the resulting seismicity. Seismicity of Iran is an evidence of the convergence between the converging plates in its southern and northern parts. A great part of the resulted deformation is divided along deformation zones like: Alborz, Zagros and Kope-Dagh. Many populated cities industrial complexes and agricultural areas of Iran have been located within the above mentioned regions. The high rate of population growth, fast expansion of the urban areas, incompatible design and construction, inappropriate planning in the cities have been increasing their vulnerability to the natural disasters specially earthquakes. Historical and recent documentations confirm the high rate of earthquake losses and damages for the communities installed within the country. During last century about a hundred thousand of people were killed, tens of thousands were injured and a huge amount of economical damages plus their consequences are left. The recent studies in Iran show that the people and economical losses have been mainly due to the failure of the residences. So it is reasonable to study the M_{max} as one of the seismic hazard parameters in Iran. The magnitude of the largest possible earthquake (M_{max}) is necessary in many seismic engineering applications. Between the different ideas including the sharp and soft cut-off maximum earthquake magnitude, that have been presented to better explain this concept, in this study M_{max} based on the sharp cut-off has been computed in order to be used in regional seismic hazard studies for different cities that has been suffered strong earthquakes during historical and/or recent times.

Keywords: Iran, M_{max} , sharp cut-off, soft cut-off, hazard parameter.

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Probabilistic Peak Ground Acceleration and Spectral Seismic Hazard Maps for South Africa

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ABSTRACT

Regional seismic hazard maps are prepared for South Africa with a 10% probability of exceeding the horizontal component of PGA and spectral accelerations of 1, 3, 5 and 10 Hz, respectively, at least once in 50 years.

The map has been computed by application of the parametric-historic procedure. The computation is done in two phases i.e. earthquake recurrence calculations and ground motion exceedance calculations. For the earthquake recurrence calculations, a system of equations has been derived for the hazard parameters using distribution models that are most often used in engineering seismology, viz. a doubly-truncated Gutenberg-Richter frequency-magnitude distribution, and a Poisson distribution of earthquake occurrence in time. Mixed data of two types are used: one containing only the largest earthquakes and the other containing data sets complete from different thresholds of magnitude upwards. For each grid point (of 0.02^{o} in latitude and in longitude) earthquake hazard parameters: Gutenberg–Richter *b*-value, and seismic activity rate, λ, is calculated. The horizontal component of the peak ground acceleration and spectral accelerations were calculated at each grid point using a modified attenuation by Atkinson and Boore (1995; 1997). In this calculation, uncertainty in the attenuation equation, earthquake magnitude and location was incorporated. A Gaussian function was applied to smooth the transitions in the data surface.

South Africa has seismic activity of tectonic origin and those that are mining-related. High levels of seismic hazard are expected in parts of the Western Cape, the Free State, Gauteng and towards the eastern border of the North West Province. Moderate hazard levels can be seen in the Limpopo Province and parts of the Northern Cape. The southern part of the Eastern Cape is subject to low levels of seismic hazard. The maps are accompanied by explanatory notes on the methodology used.

Key words: seismic hazard map; South Africa

PRESENTER'S BIOGRAPHY

Dr Kijko has been active in engineering geophysics and seismology for 34 years. His interests and responsibilities have taken him all over the world and he has a wide range of experience as a result of the various research posts and consulting positions he has held. His principal interests are in the fields of numerical and computing techniques, data analysis, and applied statistical methods. Dr Kijko has used instrumental observations along with historic, paleo- and neotectonic information to develop a methodology for seismic hazard assessment. More than 100 of his publications have appeared in academic journals. Dr Kijko is the author of a book on statistical methods in engineering seismology and co-authored a book on mining seismology. At present he is busy with a book on statistical methods in seismology, initially authored with the late Professor K. Aki.

Seismic Hazard and Risk Statistics

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ABSTRACT

Instrumental seismology is a young science, so that many of its accepted quantitative relations of earthquake size and recurrence were formulated with lacking or in the absence of data. There is growing evidence that many of the "old good" paradigms attributed to seismic activity are simply misleading to surprises like the Great 2008 Wenchuan Earthquake and require a serious revision. The applicability of the commonly used probabilistic estimates of seismic hazard and risk is really dubious, if not unacceptable. For example, the methodology of PSHA is affected by severe shortcomings, being derived from wrong mathematical and naive physical assumptions.

A constructive alternative to PSHA could be so-called neo-deterministic approach that allows integrating (i) pattern recognition techniques aimed at earthquake predictions – from termless identification of earthquake prone areas down to intermediate-term medium-range or better accuracy, (ii) unified scaling law for earthquakes that account for fractal distribution of earthquakes in space-time-size domain, and (iii) realistic modeling of earthquake scenarios. Build upon, almost exclusively, the empirical geophysical, seismic, and tectonic features of a region, scenario-based seismic hazard maps take into account the recurrence of devastating, disastrous, major, strong and moderate earthquakes with exceptional, rare, sporadic, occasional and frequent consequences, correspondingly, and, therefore, may provide more appropriate estimates for the ground motion levels to be expected in different regions of the world and time span. The high quality data from observation of the Earth (GPS, InSAR, etc.) may help compiling the displacement/deformation maps within the areas of the highest expected hazard and combining the analysis of real-time deformation patterns with routinely updated information from seismic monitoring aimed at forecast/prediction of significant earthquakes.

Key words: statistics, hazard, risk, PSHA, scenario earthquakes

PRESENTER'S BIOGRAPHY

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Seismic Hazard assessment of the Gwayi Shangani dam site

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ABSTRACT

The Lupane area is a mega shear zone of Pre- Cambrian age situated on the southern flanks of the mid - Zambezi basin in Zimbabwe. The region under consideration is bounded by latitudes 19ºS and 18ºS, and longitudes 26ºE and 28ºE. The area is characterized by lineaments and faults trending northeastwards. Two rivers, Gwayi and Shangani meet in the area. Zimbabwe is currently constructing a dam across their confluence. Since the area is highly faulted, seismicity due to induced activity is expected to increase in the area at the completion of the dam. This paper discusses the seismic hazard potential in relation to geological fracture patterns in the Lupane area. Data used for the study were obtained from the BUL catalogue for the period 1958 to the present. The standard probabilistic approach for seismic hazard assessment incorporating a quality factor of 350, to determine the attenuation coefficient, was used. A threshold magnitude of 4.0 m_b was used. A maximum peak ground acceleration (PGA) value of 0.15g was determined for the dam area.

Key words: peak ground acceleration, Hazard assessment, Probabilistic method, attenuation coefficient

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BRASSNAVY MANZUNZU'S BIOGRAPHY

Brassnavy Manzunzu (Trainee Seismologist) is a young research scientist who is currently undergoing some training in seismology. He holds a BSc Honors in Physics from the University of Zimbabwe and is working at Goetz Observatory in Zimbabwe as a trainee seismologist. He is looking forward to further his studies in seismology. His research interests are in Hazard assessment and mitigation.

Test of Seismic Hazard Map from 500 years of Recorded Intensity Data in Japan

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ABSTRACT

Maximum seismic intensity maps for Japan are constructed using the recorded intensity data from 1498 to 2007, to test the probabilistic seismic hazard map (PSHM) by the Headquarters for Earthquake Research Promotion. The historical intensity data are obtained by combining Usami's catalogue of historical earthquakes with the Japan Meteorological Agency (JMA) intensity catalogue. The historical intensity maps are compared with the hazard maps of probable maximum seismic intensity for the next 500 years, for cases associated with all events, subduction zone earthquakes, and other events (all events excluding subduction zone earthquakes). The megathrust earthquakes in the subduction zones produce large bands with high intensities along the Pacific coast side, while onshore crustal earthquakes create a patchy distribution of large intensities over all of Japan. The maximum recorded intensity map for the last 500 years and the predicted PSHM for the next 500 years are very similar for the cases of all events and the subduction zone earthquakes, while there is poor correlation for the other events including onshore crustal earthquakes. If we consider only the amount of area, not the specific location, the recorded intensity map and the PSHM in the maximum case have a high correlation for JMA intensity higher than 4 for all of the cases. Statistically the present PSHMs in Japan seem to agree with the past intensity distribution and can be regarded as appropriate seismic hazard maps, even though there may be strong dependencies on uncertain model parameters.

Key words: seismic hazard map, historical intensity

PRESENTER'S BIOGRAPHY

Masatoshi Miyazawa is an assistant professor at the Disaster Prevention Research Institute (DPRI), Kyoto University, Japan. His major research focus is earthquake seismology. He received a Ph.D. in geophysics from Kyoto University in 2003. From 2003 to 2005 he was engaged in seismic observations and analyses of disastrous earthquakes as a postdoctoral researcher in DPRI. From 2006 to 2007 he was a postdoctoral fellow at Colorado School of Mines, USA and worked on a collaborative project with ExxonMobil.

Probabilistic Seismic Hazard Analysis of the Po river levee (Italy)

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ABSTRACT

The Po river is situated in a large alluvial valley in Northern Italy characterized by a moderate seismicity. According to the Italian Historical Earthquakes Catalogue (CPTI04) the largest event occurred in the area reached a magnitude around 6.5.
We performed a seismic hazard analysis aimed at the definition of the reference input motion in order to evaluate the vulnerability of Po levees. To reach this goal we computed isoprobable hazard response spectra and seismic hazard disaggregation in terms of magnitude and distance.

We analyzed several accelerometric data bases in order to select all the accelerograms compatible with the computed hazard values to assess the liquefaction susceptibility of levees under seismic load. The analysis, according to the fact that both PGA and strong ground motion duration are important for liquefaction hazard evaluation, was conducted taking into account high magnitude distant earthquakes even if their PGA could be not so relevant.

Key words: probabilistic seismic hazard, levees vulnerability

PRESENTER'S BIOGRAPHY

Marco Pagani got a PhD in Earth Sciences at the University of Milano in 2002. After the graduation he worked for one year as a consultant and successively joined the Institute for the Dynamics of Environmental Processes of the Italian National Research Council, where, presently, he is working as a researcher.
His research activities focuses on hazard analysis of natural phenomena with probabilistic and soft computing techniques, on flexible techniques applied to geographic information systems, on data analysis and data mining techniques to assist the development of innovative materials. He participated to several national and international research project in the fields of seismic hazard, material sciences, and GIS and remote sensing.

Neo-deterministic seismic hazard scenarios for the Adria region and its surroundings

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ABSTRACT

A neo-deterministic approach to seismic hazard assessment is considered that, based on the available knowledge of the physical properties of the Earth structure and of the seismic sources allows for a time dependent definition of the seismic input, through the routine updating of earthquake predictions. In this way a set of deterministic scenarios of ground motion, which refers to the time interval when a strong event is likely to occur within a given region, can be defined at regional and local scale, thus providing information that can be useful in assigning priorities for timely mitigation actions.

Constraints about the space and time of occurrence of the impending strong earthquakes are provided by the intermediate-term middle-range earthquake predictions (performed by means of the algorithms CN and M8S) and by the pattern-recognition of the areas prone to large events. The scenarios of expected ground motion, associated with the alarmed areas are then defined by means of full waveforms modelling at bedrock, based on the possibility to compute synthetic seismograms by the modal summation technique. Among the possible developments towards a more accurate identification of the area of the impending earthquake, the analysis of real-time deformation patterns within alerted earthquake prone areas is expected to play a relevant role, where the newly available high quality positioning data (e.g., GPS and InSAR) would permit to compile real-time displacement/deformation maps within the alerted areas and to combine them with routinely updated seismic information.

An example of the integrated approach to time dependent scenarios of ground motion is provided considering the application of the mentioned methodologies to the Adria region and its surroundings. The Adria region, along with Italy, is the only area of moderate seismic activity where the two different prediction algorithms CN and M8S (i.e. a spatially stabilized variant of M8) are simultaneously applied and a real-time test of predictions, for earthquakes with magnitude larger than 5.4, is currently ongoing. The application of the CN algorithm to the Adriatic region, which is especially relevant for seismic hazard assessment in the North-Eastern part of the Italian territory, is discussed in detail. Examples of neo-deterministic scenarios are provided, at regional and local scale, for sites where the knowledge of the local geological conditions permitted a detailed evaluation of the expected ground motion.

Key words: Ground motion scenarios, pattern recognition, earthquake prediction, morphostructural zonation, Adria region

PRESENTER'S BIOGRAPHY

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Possible non-robustness of Mmax parameter and robust analogues of Mmax

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ABSTRACT

The seismic risk assessment problem is believed to be strongly connected with the Mmax value determination problem. The main problem behind estimation of Mmax value and other possible characteristics of tail of a distribution is to be able to estimate quintiles "outside the range of the data" that is equivalent to finding reliable estimators for the tail (1 – F(x)) with large x. Estimation outside of the range of the data can be made only if some additional, extra assumptions about the distribution function are imposed. To obtain such estimation we use the limit theorems of the Extreme Value Theory. The suggested method for the estimation of unknown parameters is based on the use of two limit theorems connected correspondingly to Generalized Pareto Distribution (GPD) and Generalized Extreme Value distribution (GEV). We establish direct relations between parameters of these distributions permitting to evaluate the distribution of T-maxima (maximum magnitude in sequential time interval of duration T) for arbitrary T value. In this examination we demonstrated a possible non-robustness of the generally accepted parameter characterizing the tail of magnitude-frequency law – the maximum possible magnitude Mmax, and suggest instead of it a robust parameter $Q_T(q)$ – q-quintile of distribution of T-maximum on future interval of duration T. Being applied to the Harvard catalog 1977-2006 and to Fennoscandia catalog 1900-2005 our approach had resulted in the following estimates: Mmax= 9.53 ± 0.52 and $Q_{10}(0.97)$=9.21 ± 0.20 for the global catalogue, and Mmax = 5.76 ± 0.165 and $Q_{10}(0.97)$ =5.44 ± 0.073 for the case of Fennoscandia. It is easy to see that Q parameter values are essentially more robust. We obtained as well the estimates of all related parameters for GPD and GEV, including the most important form parameter characterizing the distribution law of rare strongest earthquakes. The character of possible change of parameters of the tail of strong earthquakes distribution is discussed.

Key words: strong earthquakes statistics, seismic risk

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Engaged in natural hazards statistics, earthquakes regime, physics of earthquake origin, algorithms of pattern recognition.

Probabilistic assessment of the upper limit of the earthquake magnitude distribution $m_{\max}$

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ABSTRACT

The upper limit of the earthquake magnitude distribution $m_{\max}$ is a critical parameter in the analysis of seismic hazard and risk. Various efforts are noted in the literature in the evaluation of this parameter. In this presentation, we develop a procedure for it's assessment by employing fundamental results in the analysis of order statistics, while also making use of the information-theoretic entropy concept. Results are developed for instances where assumptions are made regarding the underlying statistical model, for example the distribution based on the Gutenberg-Richter relation is assumed, as well as when minimal or no assumptions are made, including that of independence of observations. The proposed procedure developed here is compared with those prominent in the seismic hazard literature via synthetic, Monte-Carlo simulated seismic event catalogues as well as applications to real samples.

Key words: seismic hazard, $m_{\max}$, order statistics, information theory

PRESENTER'S BIOGRAPHY

Dr Kijko has been active in engineering geophysics and seismology for 34 years. His interests and responsibilities have taken him all over the world and he has a wide range of experience as a result of the various research posts and consulting positions he has held. His principal interests are in the fields of numerical and computing techniques, data analysis, and applied statistical methods. Dr Kijko has used instrumental observations along with historic, paleo- and neotectonic information to develop a methodology for seismic hazard assessment. More than 100 of his publications have appeared in academic journals. Dr Kijko is the author of a book on statistical methods in engineering seismology and co-authored a book on mining seismology. At present he is busy with a book on statistical methods in seismology, initially authored with the late Professor K. Aki.

Seismic hazard assessment for Madagascar

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ABSTRACT

Seismic hazard analysis of Madagascar has been performed in term of seismic activity rate, Gutenberg-Richter parameters and maximum regional magnitude using the historical data from 1975 until 2007 stored at the data base of the Observatory of Antananarivo. 11 seismogenic zones have been studied applying the Probabilistic approach developed by Kijko and Sellevoll (1989, 1992) and Kijko (2004).
Among the 11 seismogenic zones studied, the zones that have been predicted to have the highest credible magnitude and highest mean activity rate are respectively Ambatofinandrahana and Famoizankova with maximum possible magnitude, 6.06 ± 0.44 and 5.91 ± 0.4. For the zone of Ambatofinandrahana, it is estimated to occur only once during 10 000 years with annual probability equal to 0.0001. Ambohitrolona appears as the zone with lowest hazard with maximum magnitude of 4.53 ± 0.34. These results are used as a base for preparing the seismic hazard and seismic risk map for Madagascar.

Key words: Madagascar, sesmic hazard, probabilistic

PRESENTER'S BIOGRAPHY

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Macroseismic database for seismic hazard study of Central Greece

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ABSTRACT

Seismic hazard analysis was performed using macroseismic intensity data in the time period 1950-1989 for the regions of Magnesia, Karditsa and Larissa in Central Greece. The existing macroseismic database 1950-1975 was updated up to 1989. During the mid-20th century, Central Greece experienced a seismic activity period consisting of a number of significant and destructive earthquakes, which lasted for 15 years. The parametric earthquake catalogues were compared and used for the discrimination between main events and aftershocks, in terms of macroseismic intensities. Each locality in the above-mentioned areas with intensity data points was subject to probabilistic seismic hazard analysis for 40 years observation period. The analysis lead to seismic hazard maps in terms of most probable intensity and intensity with various probabilities of exceedence in the next 25, 50 and 100 years. The procedure was repeated by using different time windows shifted in time within the period of study, in order to locate the least time window able to produce reliable results. Finally, the results were plotted using different techniques (krigging, natural and nearest neighbor, Voronoi tessellation), aiming at the best possible intensity distribution pattern.

Key words: macroseismic intensity, database, seismic hazard, tessellation

PRESENTER'S BIOGRAPHY

Professor Kostantinos C. Makropoulos

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Seismotectonic evaluation and Associated Stress Field in Western Nepal Himalaya and its Adjoining Regions

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ABSTRACT

The Western Nepal and its adjoining regions are most active parts of Central Himalaya in the recent time in which shallow and intermediate focus earthquakes occur mostly in between the surface manifestation of the MCT and MBT. An extremely high seismic activity is observed between the MCT and MBT since 2000 in the central part of the region which may have some bearing on future seismic hazard. The studies of seismic activity from 1963 to 2006 in relation to major tectonic feature of Western Nepal Himalaya and its adjoining regions bounded by 28°-31° N and 79°-82.3° E suggests that seismicity is non-uniform in space and time in this part of the Himalayan compression zone. It fluctuates in the form of high and low seismic phases and these events were probably triggered by the MBT and transverse features existing in the region. The analyses of fault-plane solutions of twenty-four earthquakes from 1964 to 2004 inferred that the Western part of Nepal Himalayan frontal arc is in compressed state in which seismic activity is dominated by thrust faulting. Results indicate that north-south to northeast-southwest directed compressive stress based on orientation of *P*-axes and the prevailing stress is approximately perpendicular to the major trend of the Himalaya. Thrust faulting coupled with shallow dip of nodal planes reflects that the Indian continental lithosphere is under-thrusting at a shallow angle. This information suggests crustal shortening in north-south direction in which earthquakes are generated due to northward compression. In the adjoining Tibet parts earthquake activity is due to normal faulting with east-west extension. From the orientation of maximum compressive stress, it may be concluded that the earthquake generation process in the compression zone of Himalaya is totally different than the extensional zone of adjoining Tibet region. Concentrated pattern of steeply dipping tension axes show that there is no mass movement like Tibet in the Himalayan region. The results thus derived demonstrate the present state of geodynamic process and associated stress field in Western Nepal Himalaya and its adjoining regions.

Key words: Seismic hazard, Geodynamic Process, Mass movement, Stress field

PRESENTER'S BIOGRAPHY

Dr. D. Shanker is presently an Assistant Professor of Engineering Seismology in the Department of Earthquake Engineering, Indian Institute of Technology Roorkee, India. After serving for more than 10 years in different institutions as Lecturer as well as Research Associate, he joined the University of Roorkee (presently IIT Roorkee) in year 1996. He has so far supervised one PhD thesis and three M.Tech. Dissertations. His research publications numbering more than 92 in International and National Journal of their repute as well as Conferences, have covered various field of earthquake seismology, seismic hazard and risk assessment, earthquake prediction, seismic microzonation and landslide hazard zonation, geophysical and geochemical earthquake precursor search for long term-prediction and statistical seismology and earthquake engineering. As an active consultant and researcher, he has made a great contribution in teaching to PG and UG Science and engineering students. Having, more than two decades of research and teaching experience, he has served as scientific reviewer of dozens of international and national research Journals. He has participated various international and national training program and meetings. He has also completed several research projects and consultancies. Being a life member of different scientific societies he has been invited nationally and internationally for the scientific and public lectures. Besides academics, he has made a excellent contribution in extracurricular activities and administrative skill as well, like staff adviser Rowing Game, IIT Roorkee, member of the board of examiners and Associate Manager of the senior Secondary School, IIT Roorkee. He has visited more than 16 countries on mission to imbibe technological know-how and utilized them in the scientific programmme in India.

STATISTICAL CHARACTERIZATION OF EXTREME EVENTS: AN EXAMPLE FROM AN INTRAPLATE AREA IN NE BRAZIL

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ABSTRACT

In the present paper, we fitted a Pareto Generalised Distribution (PGD) for an earthquake intraplate sequence which occurred in João Câmara, NE Brazil and was monitored continuously during two years (1987 and 1988). We used this data to assess the occurrence of extreme events in this region. In order to estimate the parameters for the PGD, we used the following methods: maximum likelihood, moment method, biased weighted moments methods and non-biased weighted moments. For the shape parameter, we used the maximum entropy method. We show that the maximum likelihood, moments and maximum entropy methods are the most efficient ones giving basically the same average squared errors. We also observed the estimated threshold for this region based on the period observed to be m_b 1.5 and also estimated the return period for 10, 50 and 100 years in this intraplate area.

Key words: Intraplate setting, seismic hazard, extreme events, seismic risk.

PRESENTER'S BIOGRAPHY

Paulo Sergio Lucio
Paulo Sergio Lucio received his B.Sc. in Mathemathics in 1987 from Universidade Federal do Espírito Santa, his M.Sc. In Statistics in 1991 from Universidade Estadual de Campinas and his PhD in 1996 from 'Institut de Physique du Globe de Paris'. From 1990 until 2002 he was a lecturer at the Statistics Department at Universidade Federal de Minas Gerais. From 2002 until 2005 he was member of the 'Instituto Superior Técnico de Lisboa' and also of the 'Centro de Geofísica da Universidade de Évora (2005)'. Since 2006, he has been employed as an adjoint Professor of the Statistics Department of UFRN. He has a research grant 2 of CNPq (Brazilian Funding Agengy). His experience concentrates in Stochastic Climatology, Computational Methods in Statistics, Geophysical simulation, Extreme events modeling and Spatio-temporal analysis.

Empirical Predictive Relations for Engineering Ground Motion Parameters on Rock Sites based on NGA Database

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ABSTRACT

Methods for estimating ground motion parameters are required since level of ground shaking for proper earthquake resistant design and thus damage potential of an earthquake can be related in terms of ground motion parameters. The better damage indicators are the parameters that can reflect nearly all of amplitude, frequency content and duration characteristics of a particular ground motion. In this study, set of empirical attenuation relationships are proposed for the prediction of various engineering ground motion parameters that incorporate in their definition previously mentioned characteristics of a ground motion. These parameters are peak ground acceleration (PGA), peak ground velocity (PGV), root-mean-square acceleration (a_{rms}), Arias intensity (I_a), cumulative absolute velocity (CAV), maximum spectral acceleration (SA_{max}), response spectrum intensity (SI) and acceleration spectrum intensity (ASI). These parameters are presented for the sites with average shear wave velocity at the upper 30 m, $V_{s30} \geq 500$ m/s representing soft rock-rock site condition.

Proposed relations are derived using 547 pairs of horizontal records obtained during 88 shallow crustal earthquakes with magnitudes 4.5 < M < 8 and epicentral distances in the range of 1km < R < 325km selected from the NGA (next generation attenuation) database because of its availability for the supplied information required and homogeneity due to the same processing procedures used. Only free-field records were used excluding records in basement of any buildings, records in the first floor of buildings with three stories or higher, records at the dam toes, crests and abutments. The records at the stations or obtained from any earthquake with missing information such as stations without two horizontal components, stations without V_{s30} definition and earthquakes without fault mechanism information were also excluded from the analysis.

Geometric mean of horizontal components are used to derive the attenuation relations for ground motion parameters previously stated as a function of the moment magnitude (M) and closest distance to the vertical projection of the fault plane (Joyner and Boore distance, R_{jb}). A term accounting for the effect of fault mechanism is included in the predictive relations. Two different functional forms for the empirical equation are selected based on a theoretical basis and the coefficients are determined by regression analysis. The proposed equations are compared with similar predictive relations and generally agree with the newest researches of NGA.

Key words: attenuation relationship, ground motion parameters, NGA Database

PRESENTER'S BIOGRAPHY

Gökçe Tönük was born in 1976 in Ankara, Turkey. She received her B.S. degree in Civil Engineering in 1998 and her M.S. in Geotechnical Engineering in 2001 both from Middle East Technical University, METU. She is currently in the Earthquake Engineering Department of Kandilli Observatory and Earthquake Research Institute at Bogazici University as a Ph.D. Candidate.

Variation of predicted ground motion in Osaka basin associated with hypothetical great earthquakes on Nankai trough

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ABSTRACT

The Nankai trough is an active subduction zone along southern coast of Japan archipelago and has repeatedly generated great earthquakes (Nankai and Tonankai earthquakes) with a recurrence period of about 100 years. The probabilities of occurring next earthquakes within the next 30 years are very high: about 50% and 60-70%, respectively. Hence, thorough prediction of ground motion is of great importance.
We conduct deterministic evaluation of possible ground motion in the Osaka basin associated with those earthquakes. Ground motion is calculated with finite-difference and stochastic Green's function methods incorporating realistic models of the subsurface structure and seismic source. Source models of those earthquakes are modified from those proposed by governmental committees by fluctuating slip distribution and rupture propagation velocity.
We generated 100 sets of heterogeneous source models for those earthquakes and simulated 3D wave propagation. Then we examined variation of ground motions calculated for the Osaka area.
As a result, the lognormal standard deviation (LSTD) of peak ground velocity ranges 0.1 to 0.3 and no clear difference are seen for LSTDs among site conditions. On the contrary, LSTDs of velocity response spectrum at natural periods corresponding to predominant periods of the Osaka basin ranges 0.1 to 0.8, and show clear spatial difference in the sediment area indicating wave interference associated with complex shape of basin structure.
These results indicate the importance of incorporating realistic velocity structure on evaluation of variation of ground motion.

Key words: deterministic approach, strong ground motion, Nankai and Tonankai earthquake, finite-difference

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