Estimating strong ground motion parameters for earthquake-resistant design

The immediate cause of havoc wrecked by destructive earthquakes is provided by the sudden collapse of human works and dwellings unable to withstand the attendant strong ground motion. Earthquake-resistant design of new structures and retrofitting of existing ones for acceptable levels of risk, therefore, constitute the primary strategy for mitigating earthquake hazards. This, in turn, requires estimates of the probability distribution of maximum ground motions in an area expected to occur in the future during the life spans of different types of structures. Fortunately, such estimates can be attempted even whilst our understanding of the earthquake process remains too incomplete to allow a reliable prediction of the exact time and place of its occurrence and size; specifically, three related problems must be addressed to accomplish this task.

The first of these consists in identifying all active faults in and around the region and determining their geometry as well as potential for generating earthquakes. The second problem calls for the estimation of ground motion time histories at a given site produced by a prescribed slip on a specified fault plane. Finally, there is the long-standing problem of abstracting a minimal set of ground motion parameters for engineering design that would be highly representative of structural damage. Globally available data and knowledge concerning these questions show the considerable progress made over the past three decades, in dealing with these problems quantitatively.

Plate tectonic concepts which have been quite successful in defining the kinematics of longer plates, thereby make the first of these questions quite amenable to rational analysis. Most of the plate boundary faults which account for a large majority of seismic energy release annually, are thus now well identified geographically. Some of these have been mapped in three dimensions to reveal their subsurface geometry using geological, geophysical and seismological mapping techniques. Even the seismic potential of some, notably the San Andreas fault have been estimated from experimentally determined plate velocities and return periods of great earthquakes inferred from exhumed fossil traces of earlier fault ruptures. Furthermore, plate tectonic concepts have been shown to provide insightful clues to estimating the seismic potential of various segments of a uniformly stressed plate boundary from a knowledge of the seismic history of only a part of it. This is especially helpful in estimating the current seismic potential along plate boundaries such as the Himalaya where return periods of great earthquakes are 400 to 500 years or even longer, in comparison to the much shorter historical record available.

The site and potential of destructive earthquakes that occur in the interior of a plate at intervals of perhaps 1,000 years or longer is, however, less easy to determine. The absence of old historical records denies any clue as to their possible location while processes of erosion during long periods of quiescence obliterate all evidences of faulting and topography formation. An ancient continent like India is scarred by numerous linear features representing early encounters between land masses that eventually led to its growth over 2 billion years ago. Some of these and perhaps others not even visible on the surface, may constitute weak zones in the crust where strain energy, leaking from the ongoing compression of the plate, accumulates in long preparation of an earthquake. The only detectable evidence that such potentially compressible zones may present at the surface, would be in the patterns of time varying strain field. Repeat measurements of baseline lengths between suitably distributed control points several tens of kilometers apart which can now be measured with sub-centimetre precision using modern CPS receivers, however, offer a promising approach to delineating such zones where anomalous strains are accumulating and to estimating their seismic potential from measured rates of strain accumulation as well as other applicable methods, notably the study of long standing precariously balanced rocks, as pointed out by Professor Brune. By providing upper bounds on estimates of recent ground motion from calculations of threshold accelerations required to topple them, precariously balanced rocks act as a veritable strong motion gauge left by natural processes, for our discernment.

New capabilities have also developed in recent years for predicting the strong ground motion histories or the ground accelerogram at a given type of geological site due to a specified fault rupture or earthquake a given distance away. This has been contributed both by the availability of new accelerograms representing a fuller range of the above-mentioned triplet variables and theoretical formulations based on the principles of fault mechanics and seismic wave propagation. In particular, the development of hybrid deterministic-stochastic models which restore the deficiency of the classical models by incorporating a stochastic representation of the details of the rupture process, show considerable promise in capturing the essential features of a real accelerogram. Besides, synthetic accelerograms provide a highly insightful tool for extending the empirical results obtained in one region, to another by the possibility of modelling the effects on ground motion caused by varying characteristics of wave propagation, near surface geology and terrain specificities.

Equally significant have been developments in the search for the most representative descriptor of ground motion which would form an adequate basis for earthquake-resistant design. In an eloquently analysed review, Hudson (*Bull. ISET paper no. 321*, 1992, **29**, 1–14) shows that none of the various parameters advocated for this purpose, notably the peak ground acceleration, velocity, RMS acceleration and spectral averages have any demonstrable superiority over the first one which is still the most widely used, and argues how we come full circle to the basic ground acceleration record as the most reliable guide for design and risk analysis of structures. He also cautions the uncritical use of the so-called effective parameters in engineering design. These can be particularly misleading when peak ground accelerations so arbitrarily doctored, are used to scale the response spectrum. Fortunately, however, the potential availability of representative strong motion accelerograms which may be synthesized, given the experimentally determined geological and seismological characteristics of the site, makes it possible for design engineers to greatly improve their design capabilities by using this unambiguous and detailed record of ground motion.

The scene would thus seem to be set for possible identification of seismically vulnerable areas and reliable predictions of ground motions using globally available knowledge and experimental approaches, to make an effective dent in the national programme of earthquake hazard mitigation in this International Decade for Natural Disaster Reduction (IDNDR). The large number of casualties suffered by the collapse of dwellings in the wake of the moderate Khilari earthquake underline the imperatives of quantifying earthquake hazard and design figures for earthquake-resistant construction and retrofitting of structures, in all parts of the country. Equally, there is considerable public concern that modern knowledge backed by hard experimental data should be brought to bear on the selection of design parameters of critical facilities, notably nuclear power systems and large dams in and around the seismic regions in view of the horrendous implications of their possible failure. The spate of structural failures of utilities in the country and the wide divergence between the opinions of seismologists and consulting engineers concerning the magnitude of potential seismic threat especially in the highly unstable Himalayan region, mainly engendered by the default in making experimental determinations of regional and site characteristics, underscore the necessity for demystifying some of the crucial issues involved in earthquake hazard quantification and its translation to engineering specifications for design.

A discussion meeting was accordingly designed by Professor R. N. Iyengar and myself to brainstorm these issues in a spirit of true enquiry marked by transparency of reasoning and assumptions. This meeting was sponsored by the Jawaharlal Nehru Centre for Advanced Scientific Research and the Department of Civil Engineering at the Indian Institute of Science, Bangalore.

The perspectives for these discussions were set by invited presentations sketching the basic outlines of the three constituent elements of strong ground motion, its prognostication and translation to engineering specifications, as well as of design engineering practices followed in the country in respect of large critical facilities such as nuclear installations and dams. Special presentations were also made to expose the findings of field investigations and failure analysis of buildings whose widespread collapse during the recent Khilari earthquake took a toll of more than 15,000 lives.

This special section contains papers presented at this meeting and would, it is hoped, generate further debate and enquiry in the continuing intellectual quest towards devising evermore effective approaches to minimizing earthquake risk to life and property in the country. We owe a debt of gratitude to Professor C. N. R. Rao, President of J. N. Centre, who visualized this possibility in sponsoring the discussion meeting.

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