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Multi-criteria seismic hazard evaluation for Bangalore city, India

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ABSTRACT

Different seismic hazard components pertaining to Bangalore city, namely soil overburden thickness, effective shear-wave velocity, factor of safety against liquefaction potential, peak ground acceleration at the seismic bedrock, site response in terms of amplification factor, and the predominant frequency, has been individually evaluated. The overburden thickness distribution, predominantly in the range of 5–10 m in the city, has been estimated through a sub-surface model from geotechnical bore-log data. The effective shear-wave velocity distribution, established through Multi-channel Analysis of Surface Wave (MASW) survey and subsequent data interpretation through dispersion analysis, exhibits site class D (180–360 m/s), site class C (360–760 m/s), and site class B (760–1500 m/s) in compliance to the National Earthquake Hazard Reduction Program (NEHRP) nomenclature. The peak ground acceleration has been estimated through deterministic approach, based on the maximum credible earthquake of $M_W = 5.1$ assumed to be nucleating from the closest active seismic source (Mandya–Channapatna–Bangalore Lineament). The 1-D site response factor, computed at each borehole through geotechnical analysis across the study region, is seen to be ranging from around amplification of one to as high as four times. Correspondingly, the predominant frequency estimated from the Fourier spectrum is found to be predominantly in range of 3.5–5.0 Hz. The soil liquefaction hazard assessment has been estimated in terms of factor of safety against liquefaction potential using standard penetration test data and the underlying soil properties that indicates 90% of the study region to be non-liquefiable. The spatial distributions of the different hazard entities are placed on a GIS platform and subsequently, integrated through analytical hierarchal process. The accomplished deterministic hazard map shows high hazard coverage in the western areas. The microzonation, thus, achieved is envisaged as a first-cut assessment of the site specific hazard in laying out a framework for higher order seismic microzonation as well as a useful decision support tool in overall land-use planning, and hazard management.

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1. Introduction

Seismic hazard, in a broad perspective, refers to any kind of phenomena related to earthquakes capable of imparting potential damages to the built and social environment. Although it is generally defined as a specified level of ground shaking, several other hazard entities such as landslides, liquefaction, tsunamis, seiches are often associated. The hazard is significantly controlled by changes in geotechnical material properties during the earthquake. In fact, site-specific attributes related to surface geologic conditions can induce considerable alterations of the seismic motions (Aki, 1988; Field et al., 1992; Nath et al., 2000; Sitharam and Anbazhagan, 2008). It is, therefore, important to deliver appropriate site-specific design ground motions for earthquake resistant structural design and the hazard appraisal. In cognizance to the existence of multiple hazard components, an appropriate decision support tool for hazard classification would incorporate of every aspect according to their likely contribution to the overall hazard. To that effect, seismic microzonation has been carried out through multi-criteria evaluation technique that accounts for several factors such as site response, shear-wave velocity, landslide, geomorphological features, besides the peak ground accelerations (Sitharam and Anbazhagan, 2008; Pal et al., 2008; Nath et al., 2008). Making improvements on the conventional regional hazard maps, microzonation of a region predicts the hazard to much smaller scales (TC4-ISSMGE, 1999; Sitharam and Anbazhagan, 2008). It involves subdivision of a region into individual areas having different potentials for hazardous earthquake effects, defining their specific seismic behavior for engineering design, and land-use planning (Anbazhagan and Sitharam, 2008b). The seismic microzonation maps are generally envisaged to provide an effective tool

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for land-use planning, hazard mitigation and management, and structural engineering applications, especially in vulnerable zones characterized with rapid urbanization and burgeoning population.

Bangalore metropolis area located at 12°58′N, 77°36′ covering an area of about 220 km^{2,} has been investigated for various seismic hazard components, namely peak ground acceleration at bedrock level, site response, liquefaction potential, effective shear-wave velocity, predominant frequency, and soil overburden thickness. Sitharam and Anbazhagan (2007a) estimated the peak ground acceleration distribution at bedrock level from synthetic ground motions for a controlling seismic source in order to present a deterministic hazard scenario. Sitharam and Anbazhagan (2007b) evaluated site amplification factor, and predominant frequency of soil columns in the region from geotechnical borehole data using SHAKE2000 (Ordonez, 2004). Anbazhagan and Sitharam (2008a) computed the average shear-wave velocity through Multi-channel Analysis of Surface Wave (MASW) surveys at 58 locations across the study region. The velocity measurements were, further, calibrated with those derived from the drilled boreholes data to generate correlations between corrected standard penetration test *N*-values and shear-wave velocity (Anbazhagan and Sitharam, 2009). Sitharam et al. (2007) investigated the overburden soil details, and the soil liquefaction potential in terms of factor of safety against liquefaction in the study region.

In the present study, the different hazard aspects are appraised in order to establish their validity and usefulness, and eventually to provide an amalgamation of the different factors in form of a hazard index map for the study region. The analysis, thus, carried out involved mapping the spatial distribution of these factors on a single reference system (1:20,000 scale resolution) using a Geographical Information System (GIS) platform; each constituting a thematic layer. Following a multi-criteria evaluation technique - analytical hierarchical process (AHP, Saaty, 1980, 1990), each theme and the features have been assigned weights and rankings respectively according to their perceived relative significances to the seismic hazard. The layers are, thereafter, integrated through spatial union to obtain the seismic microzonation map addressing a first-cut assessment of the site specific hazard to layout a framework for higher order seismic microzonation.

2. Study area and regional background

Bangalore city in the southwestern part of India come across as a vulnerable region with its expanding diverse huge population base, and extending urban infrastructure. The city is the principal administrative, industrial, commercial, educational and cultural capital of Karnataka State. It has been the fastest grown city and is presently ranked as fifth biggest city in India. Besides political activities, Bangalore hosts several national scientific laboratories, defense establishments, small and large-scale industries. The city emerged as 'the silicon city of India' with agglomeration of Information Technology corporate establishments, along with influx of thousands of software professionals every year. The metropolis represents a booming commercial venue with expansive infrastructure and diverse population that continues to accommodate the requirement of a modern urban setting. A study concerning the seismological and geotechnical issues towards providing security for the inhabitants and safeguarding the infrastructural investments is, therefore, not only significant but also essential.

Large number of earthquakes with different magnitudes has occurred often in this region (Bansal and Gupta, 1998). Recently, Ganesha Raj and Nijagunappa (2004) highlighted neo-tectonic activities in the Karnataka region and suggested the current seismic zonation of Karnataka placed in lowest hazard zone i.e. zone II of BIS hazard zonation code (BIS, 2002) to be inadequate. The regional environs of the city have been implicated with neo-tectonic and fault reactivation. A seismotectonic map depicting a circular area of about 350 km radius around the city has been depicted in Fig. 1. The active faults and lineaments along with associated seismicity in the region have been examined in following up to the previous studies of Dasgupta et al. (2000), and Ganesha Raj and Nijagunappa (2004). The seismicity is accounted for with a M_W consistent earthquake catalogue covering a period of 200 years from 1807 to 2006. The seismic activities of the relevant faults and implications to the fault-rupture patterns have been discussed in detail by Sitharam et al. (2006). The closest observable lineament extending SW–NE about 105 km with 5.2 km away from the city to the north Mandya–Channapatna–Bangalore Lineament. To the west of Bangalore, amongst several minor faults, Chikmag-

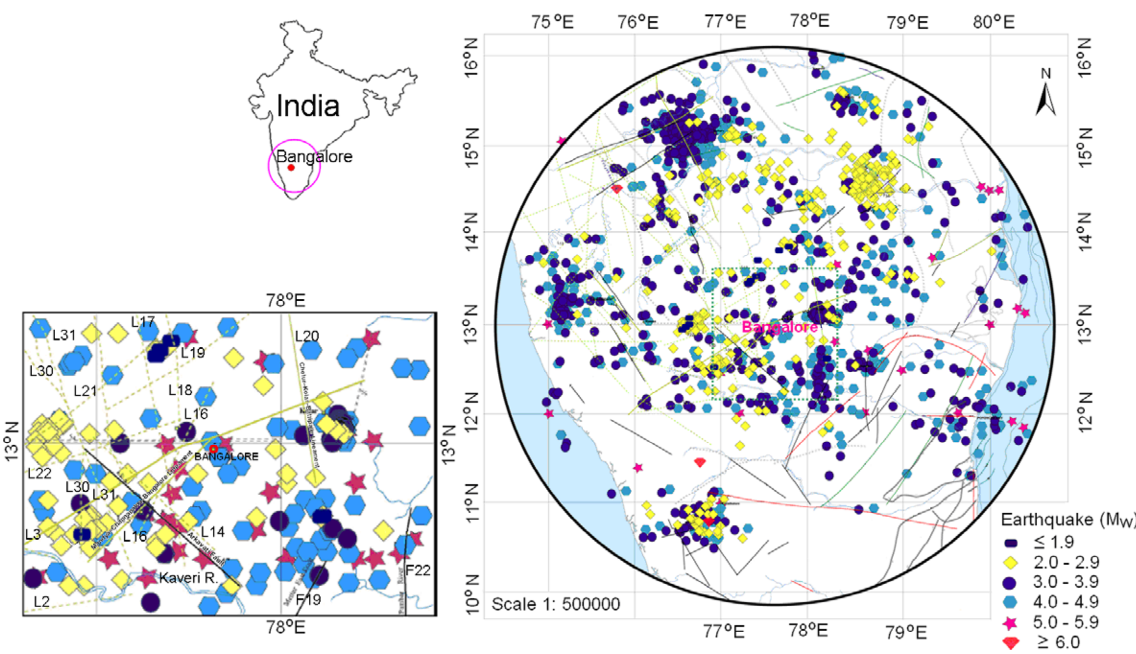

Fig. 1. A seismotectonic map of the study region depicting major linear tectonic features with the seismicity covering a period of 200 years: 1807–2006 (after Sitharam et al., 2006).

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