Journal of Rehabilitation Research
Current ISSN: 3068-9333

PRIME
OPEN ACCESS

Volume 2, Issue 2

Research Article

Date of Submission: 23, Feb, 2026
Date of Acceptance: 25 Mar, 2026
Date of Publication: 10 Apr, 2026

An Analysis of Earthquake-Prone Regions of India

V. Basil Hans*

Research Professor Srinivas University, Mangalore, India

***Corresponding Author:** V. Basil Hans, Independent Researcher, India.

Citation: Hans, V. B. (2026). An Analysis of Earthquake-prone Regions of India. *J Rehabil Res Curr Updates, 2*(2), 01-10.

Abstract

India is one of the most seismically active regions in the world due to its complex tectonic setting, primarily influenced by the collision of the Indian and Eurasian plates. This study provides a comprehensive analysis of the earthquake-prone regions across the Indian subcontinent, categorizing them into seismic zones based on historical earthquake data, tectonic features, and geological factors. The research highlights the vulnerability of northern and northeastern regions, such as the Himalayas, North-East India, and parts of Gujarat, due to their proximity to major fault lines. Additionally, the study examines the implications of urbanization and infrastructure development in these high-risk zones, emphasizing the need for stringent building codes and disaster preparedness. By integrating geospatial data and seismic zoning maps, this article aims to support policymakers, engineers, and urban planners in mitigating earthquake risks and enhancing resilience in vulnerable areas.

Keywords: Seismic Zones, Tectonic Activity, Earthquake Hazard, Disaster Risk Management. Indian Subcontinent, Seismology

Introduction

India is considered one of the most earthquake prone countries in the world. The eastern Himalaya region near Bhutan and Assam in northeastern India form one of the most seismically active areas; the Indo-Gangetic plains (including the Kolkata area) and the Gujarat region near northwestern India are the other areas susceptible to earthquakes. Justification for this classification is provided by the fact that India witnessed four great earthquakes in the past 58 years (1897, 1905, 1934, and 1950). Other medium-magnitude earthquakes also occurred from time to time, including the Koyna earthquake in 1967. Earthquake risk assessment methods involve qualitative and quantitative analyses based on physical, social, economic, and geographical information. The qualitative method examines empirical relationships and historical earthquake data to identify areas of major risk, while the quantitative method employs numerical data on ground motion, site response, liquefaction possibilities, geological positions of fault ruptures, local geology, and geotechnical factors.

India lies at the convergence of three major lithospheric plates, namely the Indian plate, which is moving roughly northeastwards; the Tibetan plate, which is almost stationary; and the Eurasian plate, which is moving eastwards. The northward motion of the Indian plate toward the Tibetan plate, at about 5 cm per year, is responsible for mountainous uplift and creating seismic activity in the region [1]. India has been divided into four seismic zones following the Bureau of Indian Standards (BIS) 1893 1962 classification: Zone I, the region of the lowest seismicity; Zone II, the region of low seismicity; Zone III, the region of moderate seismicity; and Zone IV, the region of high seismicity. Zone IV comprises the entire Himalaya region, Himachal Pradesh, the Punjab region of Kashmir, some parts of Rajasthan, the Rann of Kutch region of western Gujarat, the northeastern region including the union territories of Andaman and Nicobar, and parts of western Uttar Pradesh.

Geological Background

The Indian subcontinent slides northward into the Eurasian plate at a rate of approximately 5 cm/year, leading to the formation of the Himalayan range and the Tibet Plateau [1]. Analysis of data from seismological networks indicates that eastern India has higher seismicity than western India; however, western India has a larger number of major earthquakes [2].

The seismicity of India has been divided into five seismic zones. Zone 5 includes the Himalayan belt and the north and northeastern states. Zone 4 consists of the Rann of Kutch, Delhi and surrounding regions, and the west coast. Zone 3 covers the Ganga plain, southern peninsula, and some parts of the western Deccan Plateau. Zone 2 includes the central shield area where very few earthquakes have occurred. Zone 1 encompasses the remaining stable parts of the Indian Peninsula. Zone 5 experiences occasional earthquakes with magnitudes exceeding 8, while zone 4 has witnessed major earthquakes with magnitudes around 7.5.

Tectonic Plates and Earthquake Activity

Earthquakes wax and wane on a variety of timescales yet provide a constant source of wonder and awe. More than 20,000 earthquakes are recorded annually, but most are generally small and go unnoticed. However, there are giant earthquakes that dramatically impact communities and can influence natural systems for days and weeks. Earthquakes can damage infrastructure and claim many lives and are the focus of intense monitoring, investigation, and scientific scrutiny to better understand earthquake hazards, especially in India, which is located in the collision zone of the Indian and Eurasian Plates.

Seismic Zones of India

The Himalayan arc houses some of the world's highest mountains and is closely associated with intense seismicity. Occasional large earthquakes starting a long cycle are followed by basins coming again. However, most parts of the Peninsular India are categorised under Zone II (Table 2.1), the far-field of the Himalayan collision, whereas a small northwestern region near Kutch falls in Zone V. Zone V is the highest susceptible zone for a larger destructive earthquake of magnitude above 7.5 or even as high as 8.5. The peninsular parts of India are not completely free from earthquake hazard as some of its regions are seismically very active and others are moderately active.

Historical Earthquakes in India

India's historical earthquake catalogue contains multiple tests of a model predicting the regional distribution of large earthquakes that is based on location and mechanism of smaller magnitude events [1]. India has historically experienced severe earthquakes that caused significant loss of lives, properties and environment [2]. Major earthquake-prone regions include: The Sub-Himalayan Region; The Western Margin of the Indian Subcontinent; The Indo-Gangetic plains; The Northeast region of India encompassing the entire North Eastern Hill (NEH) States [3]. Cracks on or damage to different classes of buildings reveal that the existing provisions of earthquake resistant design of IS 1893 (Part 1): 2002 need further modifications, highlighting the need for structural mitigative measures for existing buildings. Retrofitting of specific vulnerable elements and judicious application of structural details in new constructions may enhance the resistance of masonry structures against earthquake forces. A study of emergency preparedness plans at national and local government levels and their compatibility with risk reduction strategies further underscores the significance of non-structural mitigation efforts.

The 1934, 1897 and 1950 earthquakes stated above had tremendous effects on human life and property in the North-Eastern region of India. With the help of the compiled earthquake data, a re-evaluation of seismic hazard of Tripura and Mizoram States has been performed after homogeneously re-scaling the available earthquake magnitude to Ms-Unit. The area was divided into six seismic source zones based on seismicity, fault mechanism, magnitude and depth distribution of past earthquakes. On the historic and instrumental catalogue, a qualitative and quantitative assessment of the risk of earthquake-induced Large Landslides (LL) has been carried out using the National Landslide Database.

Major Earthquakes and Their Impact

Between 1897 and 2004, India experienced more than 15 major earthquakes with magnitudes greater than or equal to 7. The 1897 Shillong earthquake of magnitude 8.0 devastated roughly 5600 km2 of prominent structures. The 1988 Bhutan earthquake of magnitude 6.2 affected 11 out of 20 districts in Bhutan. The 2001 Bhuj earthquake of magnitude 7.9 destroyed the Kutch area. To understand the history, magnitude, and damages incurred as a result of these major earthquakes, detailed documentation has been prepared. Now that the location of future earthquakes is known, assessing their impacts on the development and stability of infrastructure is imperative. A quantified approach to risk assessment is desirable because it enables comparison of different projects, regions, and time periods to provide relative evaluations [2].

Damage patterns of the Bhuj earthquake reveal that significant ground shaking was observed in the epicentral area. The Kachchh–Saurashtra region experienced severe damage, and MODERATE damage was reported in southern Rajasthan and some areas of Gujarat unsealed by outline NO. The degree of damage greatly depends on the shaking intensity, which diminishes with increasing distance from the epicenter. Unsuspected isoseismal contours extend to the margins of the maximum damage zone, further indicating the spatial distribution of the impact [4].

In response to the impact of the 2001 Bhuj earthquake, microzonation studies were conducted for Delhi, Jabalpur, and Dehradun. The seismicity of the Delhi area is documented, providing insights into regional seismic activity. Additionally, the Vulnerability Atlas of India (1999) by the Building Materials & Technology Promotion Council outlines earthquake vulnerabilities nationwide, focusing on the effects of major earthquakes in the region [3].

Lessons Learned from Past Events

Several major earthquakes in the past century serve as a reminder that seismicity is an important issue of concern. The vulnerability of major buildings in India, particularly in cities like Delhi, Jabalpur, and Dehradun, and of lifelines such as rail/road, water supply, electric supply, sewage, communication, dams, hospitals, schools, and vulnerable industries, requires attention. No assessments have been conducted concerning safety zones, safe structures, and secure routes that would aid the administration and public in facilitating relief and rescuing.

Risk Assessment Methodologies

Risk assessment studies assess the potential impact of natural hazards on people, property, and the environment, form the first and most important step of a preparedness program for disaster management. In some situations and regions, little detailed data exist for the estimation of earthquake hazard parameters and therefore, a systematic deterministic approach through the time know-how on earthquake occurrences can provide reasonable methods. Two engineering approaches to risk analysis are qualitative/semiquantitative, on one side and quantitative, on the other side. In the qualitative or semi-quantitative approach the assessment of damage is based on a series of damage predictors of various nature. The earthquake magnitude shows the amount of energy released during earthquake motion and can be used to scale the intensity and extent of damage from one event to another. Certain regions with similar geological characteristics are also more vulnerable than others for the same event; conditions which are difficult to assess in a rigorous way are sometimes considered accordingly in this approach. The quantitative approach is well defined within the framework of the risk analysis procedure. Extensive interpretations and extrapolations, which are essential for the attainment of results and have a well established physical meaning, are accomplished within this framework. Considerable experience with this method indicates that the rigorous treatment of uncertainties adds a substantial reliability to the method and provides a better evaluation of risk-parameters [2]. Seismic hazard assessment is important for determining the level of earthquake resistant design and also for planning and management of engineering activities. A low level of risk obtained from a seismic hazard study does not necessarily indicate a low level of earthquakes, but is a measure of vibratory ground motions at different locations and the ability of the geological and tectonic environment to generate earthquakes. A large number of earthquakes either of small or moderate magnitudes could be occurring in an active zone, but not capable of producing large magnitude events leading to harmful vibrations at a site of concern [3].

Qualitative Risk Assessment

Risk assessment generally implies an estimation of the area of vulnerability of a region to an earthquake and provides an indication of the expected level of losses. A formal risk assessment also shows the available options for reducing the risk and the resulting benefits of these options. Risk is generally measured as a combination of expected damage to property, loss of human lives and disruption of business in the area [2].

Risk assessment can be performed by either qualitative or quantitative methods. In quantitative risk assessment, numerical estimates of risk are made in terms of losses. This method requires much data on the type of construction, value of the property, cost of societal disruption, etc. In qualitative risk assessment, the nature and extent of risk is described. This method requires less data but provides only approximate estimates of losses, relative ranking of risk or types of construction to reduce risk and protect life [3].

Risk can be expressed in terms of a positive function, R, which is dependent on a number of other functions. One of the functions on which risk depends is the vulnerability function for a particular type of construction in the region under consideration. These vulnerability functions describe the potential for loss of life and property consequent upon an earthquake shaking of different intensities.

Numerous investigations of the potential effects of strong ground motion have been conducted over the years. As a result, simple systems applicable to specific types of construction and other common elements have evolved that can be combined in many ways to provide estimates of relative risk. The degree of sophistication of the calculated risk can be no more accurate than the input parameters [5].

Quantitative Risk Assessment

Recent decades have witnessed substantial efforts to develop seismic risk methodologies, broadly categorized as qualitative and quantitative [2]. Qualitative assessments incorporate historical earthquake records, active fault identification, urban growth and patterns, and geophysical, social, and other parameters. Quantitative approaches, in contrast, aim to estimate the annualized expected economic losses from earthquake scenarios—where the time of occurrence remains unknown—through a combination of probabilistic hazard estimates with diverse inventory and vulnerability data [5]. Employing the concept of scenario ensembles, future seismic risk variations and sensitivities to prevailing assumptions can be evaluated with high temporal and spatial resolution. This framework provides valuable insights that complement traditional seismic hazard and risk analyses of active regions [3].

The 2011 seismic risk assessment of Agartala and Aizawl adopted the deterministic seismic hazard as a foundational parameter for risk estimation. Analytical considerations included various aspects of individual building geometry exhibiting diverse seismic responses, reinforcing the significance of regional risk microzonation—particularly for the rigid buildings characterizing populous Indian regions. During recent earthquakes, improper construction exacerbated structural damage. Complementing seismic microzonation, vulnerability classification based on urban structural characteristics therefore holds considerable potential for improved risk evaluation.

Because earthquake impacts cannot be entirely avoided, assessing and reducing seismic risk in terms of human and economic losses becomes imperative. Although seismic risk assessments have advanced considerably, risk microzonation studies continue to receive inadequate attention. Earthquake-resistant construction codes for new buildings have been implemented in India; however, existing urban structures remain unaddressed apart from the Historic City of Delhi, underscoring the necessity of retrofitting efforts and community preparedness. The National Housing and Habitat Policy, introduced by the Ministry of Urban Development and Poverty Alleviation, Government of India, aims to promote awareness, prevention measures, and capacity building as integral components of long-term seismic risk reduction strategies.

In examining the relationship between seismic hazard variations and seismic intensity measures, the concept of scenario ensembles emerges as an effective tool. Analysis of these variations, complemented by relative seismic risk derived from such methodology, sheds additional light on the district-level risk associated with different estimation approaches. Results indicate the presence of various geophysical, historical, and demographic factors influencing relative seismic risk. Positive space-time correlation of these factors can therefore inform disaster reduction and preparedness strategies at appropriate scales.

Vulnerability of Structures

Vulnerability refers to the predisposition of buildings and facilities to incur damage during any kind of earthquake. National assessment studies indicate that about 15 million housing units made of loadbearing masonry could be vulnerable to earthquakes [3]. Pre-independence constructions are prone to collapse because their design was based on code provisions and earthquake-resistant concepts that are inadequate by twenty-first century standards. Even recent constructions of state-of-the-art design can be vulnerable if the earthquake-resistant system is damaged beyond its post-elastic limit. Vulnerable housing and other critical infrastructure can be assessed by carrying out vulnerability studies. Most of the structures constructed in seismic zones IV and V in the Hilly Regions are vulnerable to even a moderate intensity earthquake. Additional analysis provides design modifications and guidelines for strengthening existing quasi-vertical buildings without having to compromise on the architectural features specified by the user. Such efforts constitute a typical retrofitting exercise, which refers to the evaluation and subsequent upgrading of a structure with the primary intention of making it safer during an earthquake [2].

Building Codes and Standards

Building codes and standards underlie seismic-resistant building construction. Although seismic design formulations are incorporated in the codes, these are yet to be fully enforced. Because of the heterogeneous characteristics of soil, water table, and material characteristics across a large region, the design of individual elements for a given zone value may not always be appropriate; detailed microzonation site-specific design rating is becoming important when precision is desired [3].

Retrofit of structures can reduce the likelihood of collapse, yet research on improvement techniques that are quick, cost-effective, easy to apply, and robust is still in progress. Strengthening approaches for masonry housing, considered more vulnerable in India, remain indirect and have not yet attained credibility [6]. Clear guidelines for effective strengthening of masonry houses are still unavailable. The evolution of design codes has gradually expanded their coverage, but the heterogeneous nature of practice still needs to be addressed. There is a need for simplified, concise, and reliable design codes or methods, which might be achieved by separating safety considerations from the main design process or by specifying easy-to-follow procedures for key design considerations.

Retrofitting Techniques

Retrofit provides valuable technical and organizational information relating to techniques, procedures and materials for the seismo-techno-economic strengthening of, for example, non-engineered constructions. Several high-performance retrofitting techniques can be applied to reinforce non-engineered civil structures such as foam mixing flooring, FRP, CFRP blocks, claddings, tie columns, shotcrete, multiple plies and other innovative materials at a lower cost. Such materials can help improve overall construction quality, carry the load safely and increase the quality of the structural space to resist earthquake loading. The retrofitting of rubble stone masonry walls with various types of steel and CFRP materials shows a considerable improvement in terms of the effective energy dissipated [3].

Preparedness and Mitigation Strategies

Preparedness and mitigation strategies encompass the emergency planning of activities and programmes to reduce the impact and severity of an earthquake. Since earthquakes occur without warning, a comprehensive and effective disaster management system is essential for reducing human and economic losses. Awareness and preparedness are essential at all governmental and public levels, necessitating a coherent and well-planned disaster mitigation approach. Emergency response planning for earthquakes includes immediate measures to aid survivors, restore order, and conduct damage assessments. It involves pre-disaster activities to alleviate impacts and reduce overall risks. A strong rescue and relief capability constitutes the foundation of earthquake disaster management. Additionally, preparedness addresses the vulnerabilities of structures during seismic events [7].

The implementation of mitigation and preparedness policies and programmes enables communities to provide effective and timely assistance to affected populations. Measures include extensive training for groups, government officials, and local non-governmental organizations involved in disaster relief and rehabilitation efforts. Maintaining and rehearsing emergency action plans is critical to ensure their efficacy [2].

Emergency Response Plans

Developing functional plans for disaster response remains necessary not only at the isolated building level but also at the provincial and city-wide levels to reduce economic and human consequences associated with potential earthquakes. In pursuit of the latter, the objective of Emergency Response Plans is to establish the framework for the development of an effective pre-disaster planning system that incorporates existing ongoing efforts at several levels [8]. Emergency response plans can serve as the foundation for the creation of strategies to reduce, respond to, and recover from disruptions caused by natural hazards. They establish the framework for these goals while allowing authorities to tailor strategies to various environments and situations. The management of such hazards has progressed through the identification of key functional units that provide a significant number of vital services during and immediately following an event. These include communication, emergency services, public works/utilities, health and medical services, government services, and evacuation and recovery logistics.

Public Awareness Campaigns

The Disaster Management Act of 2005 emphasizes that public awareness of the dangers of earthquakes, artificial tremors, and tsunamis is the first line of defence against catastrophic loss, injuries, and economic damage. Memorandums of Cooperation (MOCs) have been signed to exchange information, advice, and training in support of disaster preparedness; these support ongoing efforts to promote awareness of earthquakes and tsunamis and to facilitate the exchange of information among countries. The establishment of Regional Science Centers, which was started by the National Council of Science Museums, hints at the importance of such establishments in providing reliable science communication and contributing to community resilience. Awareness generation in at-risk areas is a high priority, with an interactive outreach programme designed to reach school teachers and children and a public awareness brochure on earthquake hazards and mitigation [3]. A community-based intervention study in South Delhi, a highly vulnerable area, assessed the effectiveness of imparted awareness on earthquake preparedness among residents. The study randomly selected 300 households from 30 wards, with data collected through baseline and posttest assessments and a structured questionnaire [9].

Case Studies of Affected Regions

Seismicity of the hollows and scarp like features of the Himalayan region is a manifestation of the ongoing convergence between the Indian and Eurasian plates [2]. One of the most prominent geodynamic subduction zones of the Indian plate lies along the western coast of India, which is also known as the Kutch–Gujarat–Cambay region [1]. The third seismically prominent region of the country includes the North-Eastern states of India comprising of the North-Eastern Himalayas and the Arakan–Yoma part of Burma.

The Himalayan mountain arc formed due to the collision between the Indian and Eurasian plates. The relative motion of the Indian plate is towards the Northeast direction at a rate of 5 cm/year. The ongoing collision is responsible for the subsurface dislocations and accumulation of stress in the subdivision of the study area. The African shield in the western part of the Indian plate and the Himalayan foreland basin in the north isolate the western port of the Indian plate along which strain accumulates, as evident from the strong 2001 Bhuj earthquake.

The characteristics of earthquakes in the Kutch, mainland Gujarat and the Northern part of the Gujarat region are different. This efficiency is a result of the interception of the flow of strain from the spreading ridge in the western Indian Ocean by the active fracture zone and the rift basin. The Arakan–Yoma section of Burma and the North-Eastern Himalayas is the boundary between the main Eurasian plate and the Indo-Burmese plate which accommodates the strain generated by the convergence of the Indian plate towards the east. The surface expression of the Himalayas is one of the most prominent signatures of the ongoing these geological processes.

Himalayan Region

Seven states spanning the Himalayan region were affected by earthquakes. The area is among the world's most earthquake-prone regions, having endured many large, devastating events. The geological and seismological characteristics of the region and the application of those data to disaster-risk reduction are presented to assist emergency management in the aftermath of future earthquakes and to suggest priorities for face-to-face outreach and earthquake education programmes.

India is situated in one of the most seismically active regions of the world. Movements of the Indian, the Eurasian and the Burmese plates at the northern boundary cause severe earthquakes along the 2,360 km-long Himalayan Range. Twenty-seven prefecture-level regions within seven states are prone to earthquakes [2].

The formation of the Himalayan Mountains resulted from the collision of the Eurasian and Indian plates, complete by about 40 Ma [11]. The contemporary pattern of relative plate motion now possesses a large strike-slip component parallel to the mountain belt. This observation prompts interest in the role of inherited structure and the continued effects of collision on each of these active earthquake ranges.

The Himalayan entry into the "subduction-collision" process is well documented by the youthful character of summit elevations and the lack of older detritus available to propagate the mountain front. Indian motion along this part of the Sula block results in compression and mountain building. Consequently, this region possesses a major mountain range accompanied by seismicity, although recent thrusting is not recorded in the offshore sedimentary record.

Western India

Western India, recognized as a moderately earthquake-prone area, encompasses the Kachchh seismic zone [1]. The distribution of intensities from various-sized events of the past indicates substantial rupture potential in the Kachchh seismic zone, posing hazards to the region. The state of Gujarat, positioned within this zone, harbours a significant number of villages, towns, and modern infrastructure that necessitate seismic preparedness given the area's activity. Large parts of Rajasthan and Madhya Pradesh also fall within moderate to lightly active seismic zones. Earthquakes have affected these regions sporadically, although no severe consequences have resulted from the occurrences.

Northeastern States

The northeastern states of India—comprising Assam, Meghalaya, Manipur, Mizoram, Tripura, Nagaland, Arunachal Pradesh, and Sikkim—are persistently threatened by seismic hazards arising from various active tectonic and geological processes [10]. This entire region is seismically vulnerable and falls within seismic zone-V, the highest category assigned by the Bureau of Indian Standards [2]. Approximately 80% of the land area of Assam and the Arunachal Himalaya falls under zone V, while the rest of Arunachal Pradesh and the remaining northeastern states are designated as zone IV. These states have a long history of experiencing earthquakes, with events ranging from great shocks to moderate tremors and aftershocks.

The primary geological formations include the Assam Valley, the Shillong Plateau, the Mikir Hills, and the Garo Hills. The Assam Valley is a broad, north-trending tectonic depression filled with thick alluvial deposits and enclosed on three sides by hill ranges. The valley holds significant petroleum reserves and has an extensive network of tributaries flowing southward into the Brahmaputra. The Shillong Plateau constitutes a plateau level bounded by steep escarpments on three sides; the northern escarpment, known as the Great Fault, extends from the Manas River in the west to the Kopili Fault in the east. Except for the southeastern portion, the plateau remains an elevated and relatively undissected topography. Just south of the plateau lies the Mikir Hills, a dome-shaped elevated hill mass.

Role of Technology in Earthquake Monitoring

The development of earthquake monitoring instruments fulfilling the need of collecting long time series data for seismological parameters, accurately and consistently, has become very essential in today's world. Various types of seismographs are available to serve the purpose of continuously recording Earth vibrations. Earthquake data for India is obtained from many national and international seismological agencies and is processed so as to perform comprehensive regional seismic hazard studies. The data homogenization and declustering sequentially remove foreshocks and aftershocks from the catalogue prior to analysis. Recent conversion relations help in unifying the magnitude scale for the North-East Region of India. MATLAB codes are involved in earthquake data analysis and study of long-term hazard when topical recommendations or guidelines are not available for application. The whole region is divided into several seismic source zones based on seismicity characteristics, fault rupture mechanism, earthquake magnitude, and depth. From a methodological standpoint, seismic sources have been identified and characterized as line, point, and areal sources, using the Seismotectonic atlas as a primary reference for the PAZ zone sources. Tectonic features and seismicity events are superimposed on the map, resulting in a Seismotectonic Map with a 1:1 million scale for the entire Northeast India. Both deterministic and probabilistic approaches are applied in seismic hazard assessment, accounting for uncertainties related to seismic source, earthquake magnitude, epicentral distance, and local site conditions. Established attenuation relationships provide estimates of ground motion parameters, highlighting the concentration of seismic activities near plate boundaries and subduction zones [2].

Additional monitoring instrumentation is necessary for river valley projects in the Himalayan Region, which lies within a high seismic risk zone associated with active faults and shear zones. Observations through continuous instrumentation are imperative for dam planning, enabling the assessment of seismic status before construction and facilitating the study of structural responses to seismic events after reservoir impoundment. The installation of seismological observatories in advance of construction and the continuation of observations thereafter yield valuable data that can contribute to possible earthquake prediction and enhance understanding of seismic behavior in regions with active faults [13].

Seismographs and Data Collection

Seismographs, or earthquake seismometers, are the most effective instruments for detecting earthquakes and earthquakes-related phenomena reliably. These instruments are capable of recording earthquake movements at great distances, enabling the collection of continuous records of seismic vibration. The data from seismographs provide a basis for earthquake analysis including location, magnitude, and intensity assessments [2].

Seismic data are collected worldwide and are available from various agencies including the International Seismological Centre, United States Geological Survey, National Geophysical Data Center, and Incorporated Research Institutions for Seismology, as well as national agencies such as the Indian Meteorological Department (IMD) and the Geological Survey of India. Such data underpin methodologies for defining earthquake-prone areas. Following an earthquake event, data are collected by networks of seismic stations measuring ground motion. The analysis of these data guides emergency response, safety evaluations of infrastructures, and directs danger assessments [3].

Multiple seismic stations, equipped with accelerometers and seismometers connected to the Global Seismographic Network (GSN), record ground vibrations continuously; they also maintain archives of historic seismic events. The network captures information ranging from varying scales of seismic activity and timed events. The collected data within specific regions can be studied to determine the characteristic ground motion hazard, which informs the formulation of seismic design provisions or other appropriate guidelines.

Predictive Modeling Techniques

Indian subcontinent is highly earthquake-prone, ranking 5th worldwide. According to the Bureau of Indian Standards, it extends from Himalayas to Gujarat and part of Rajasthan [2]. Forty per cent of the country is vulnerable to earthquakes of magnitude >6, 55% to magnitude 6–6.9, and 12% to magnitude less than 7. Devastating quakes—2001 Bhuj, 2005 Kashmir, 2006 Sikkim, and 2011 Sikkim—exhibited magnitudes of 6.9, 7.6, 5.1, and 6.9 respectively; damage in Himalayan and Northeast regions underscored the need for robust methodologies to predict seismic events (Pasari and Mehta, 2018). Precise forecasting remains elusive, necessitating continuous research. The present study reviews predictive modeling methods, offers comparative analysis, and suggests improvements.

Government Policies and Initiatives

India has experienced several devastating earthquakes in recent decades. Between 1988 and 2005, seven moderate-to-strong earthquakes claimed more than 25,000 lives and rendered almost a million houses uninhabitable. Over 95% of the fatalities occurred in non-engineered houses constructed without qualified design. The seismic hazards are well recognized, and many seismic-risk mitigation policies and programs are in place. Nationwide building codes have been in effect since 2001. The government has taken initiatives to improve disaster-preparedness and mitigation capabilities, including awareness and training schemes for local governance [8].

National Disaster Management Framework

The National Disaster Management Framework delineates a strategic roadmap for disaster risk reduction and holistically encompasses mitigation, prevention, preparedness, and response. India, as one of the most earthquake-prone countries, confronts substantial human loss owing to the absence of comprehensive hazard and disaster prevention and mitigation provisions [3]. Considering that the Nation embraces multi-hazard risk, the National Disaster Management Framework incorporates risk reduction measures as a fundamental constituent.

The Framework enunciates recommendations articulated in straightforward and practical terms, with the objectives of hierarchically structuring a National Disaster Management Plan; emphasizing the integration of risk reduction into all developmental endeavours; ensuring well-crafted and regularly revised disaster preparedness and response plans at various administrative levels; enhancing public awareness; fostering greater responsibility and accountability among stakeholders; promoting a culture of prevention and resilience; organising sustained training and capacity-building programmes; advancing information management and dissemination; encouraging a multi-sectoral approach; and instituting a robust monitoring and evaluation system. Crucially, the Framework underscores the persistent imperative of guaranteeing full-time dedication to the augmentation of both the capabilities and the legal obligations assigned to the disaster management directorate [12].

State-Level Initiatives

Several states prepared Disaster Management vision documents outlining programs to reduce the impact of disasters, based on central governments guidelines and experiences of some affected states. Some of these states also prepared action plans. To accelerate professional development on disaster management, particularly in dealing with earthquakes, the National Institute of Disaster Management (NIDM) set up the United Technologies Centre for Disaster Mitigation India (UTCDMI) in New Delhi. This center aims to reduce earthquake disasters through networking and collaborative efforts.

State governments conducted training programs for officers and volunteers to raise awareness of the consequences of various natural and man-made hazards—and how mitigation capabilities can reduce risks and safeguard lives, property, and the environment. The view emerged that establishments along vulnerable roads and areas should adopt the new seismic code for design and construction and maintain up-to-date disaster preparedness procedures. There is an urgent need to prepare a Disaster Management action plan emphasizing elements such as preparedness coordination and communication; vulnerability analysis and identification of high risk areas; process and procedures; recovery and restoration plan; adoption of latest hazard-resistant provisions, seismic codes, and guidelines; emergency response and evacuation procedures; training and capacity building; raising community awareness and preparedness through education, orientation, and campaign; and facilitating preparedness through prioritization of road or route infrastructure vulnerable to multi-hazards and designating safe zones for relief and dispersion [3].

Community Involvement in Disaster Management

Active engagement of the community in disaster management represents a vital strategy for earthquake mitigation. Training efforts aim to equip various segments of society with techniques for effective disaster and casualty management. Communities trained in disaster preparedness can assist injured and helpless individuals and support injured rescue personnel. Responsibly trained community members contribute positively to rescue efforts, succeeding where untrained individuals might hinder.

Local non-governmental organizations (NGOs) have proven instrumental in conducting community-based training programs. Following the 1993 Latur earthquake, several NGOs organized initiatives to impart earthquake-awareness knowledge domestically and within institutional settings. Similarly, in the wake of the 2001 Bhuj earthquake, about forty-five NGOs coordinated widespread training and assistance endeavors. Community involvement, therefore, emerges as a critical component of disaster-management frameworks [10].

Training and Capacity Building

Earthquake preparedness in India, a country highly vulnerable to multiple natural hazards, depends fundamentally on comprehensive capacity-building and training strategies at all societal levels. The National Disaster Management Authority (NDMA), supported by community organisations and non-governmental organisations, recognises the critical roles of organised national enterprises and effective local administration [13]. Scope for improvement remains, however, in defining responsibilities and streamlining administrative functions to support coordinated district and national responses. Effective response depends on national and local institutions at both district and community levels, including medical services, voluntary organisations, and facilities such as transport, communications, water, and power. Consequently, capacity building contributes in diverse ways, including stockpiling equipment, developing information systems, providing training to first responders and technicians, drafting standard operating procedures, and identifying key agencies and personnel for effective mobilisation.

Structured and comprehensive capacity-building initiatives localise and confer context specificity to national programmes. A capacity-development model for disaster preparedness, designed in accordance with the Sendai Framework's Monitoring Indicators and the institutional framework of the Disaster Management Act, enables contextualised assessment of strengths and weaknesses. An associated capacity-development index, constructed from measurable indicators of preparedness, not only clarifies the current ability to respond to impending disasters but also facilitates the evaluation of trends and gaps. This informs the equitable allocation of human and financial resources to the most needy districts. Capacity building and training remain fundamental components of wider capacity-development efforts, vital for the effective operation of a comprehensive earthquake-mitigation strategy. Specialised on-site training sessions, field surveys, participatory assessment, and measurement must include requisite knowledge of seismic phenomena, risk assessment, microzonation applications, risk mapping, evacuation techniques, and recovery strategies, as well as operational information on well-being packages, health and hygiene, and the psychosocial impact of earthquakes [3]. Personnel possessing such expertise, deployed throughout India, enhance emergency response and assist in the provision of state- and national-level institutional support.

Role of NGOs and Local Organizations

Local organizations and nongovernmental organizations (NGOs) play a pivotal role in disaster preparedness and mitigation efforts. In the immediate aftermath of a disaster, they provide assistance to those affected. An effective disaster management framework requires well-trained local organizations and NGOs capable of managing rescue, relief, and support operations efficiently. Ensuring the survival of the community becomes a collective responsibility involving national and local governments, rescue teams, the armed forces, NGOs, community groups, and the private sector [14]. Training community-based organizations empowers populations at risk to undertake rescue, relief, and rehabilitation initiatives in partnership with official authorities. Historical accounts and current data indicate that no country, regardless of its level of development, can fully prepare for natural disasters without collaboration with regional and international entities. Such cooperation includes sharing information and coordinating aid from various national and international sources [15].

International Collaboration and Support

As part of promoting international collaboration, India participates in the Inter-Government Panel for Disaster Management and the Inter-Agency Task Force on Disaster Reduction. India contributes to the Global Disaster Relief Network and international search and rescue teams, and the government grants No-Objection Certificates for aircraft and ships engaged in humanitarian and rescue operations. India also offers disaster relief support to other countries during humanitarian crises. During the January 2001 earthquake in Gujarat, contributions were received from several countries, including the United States, Canada, Germany, France, the United Kingdom, Russia, and Japan [2,3].

Global Seismological Networks

Seismic monitoring consists of measuring ground motions produced by earthquakes, explosions, and other sources of energy, in order to locate the sources and estimate their characteristics. Seismology investigates the propagation characteristics of seismic waves generated by an impulse dynamically disturbing the earth [1]. Real-time microearthquake monitoring systems installed in both near-source and far-field regions provide an efficient tool to capture pre-signatures of a major earthquake, while additionally serving as a database for regional seismicity. Instant detection of a seismic event and estimation of its location and magnitude are necessary to assess the risk and trigger early warning [2]. Worldwide seismic networks have been installed for monitoring earthquakes and underground nuclear explosions and are operated under the aegis of the International Data Centre of the Preparatory Commission for Comprehensive Nuclear-Test-Ban Treaty Organization. This global network comprises sixteen primary stations and approximately sixty auxiliary stations distributed throughout all continents: Africa, Asia, Australia, Europe, North America, and South America.

Aid During Natural Disasters

Disasters—catastrophic events causing widespread resource shortages, loss of life, and property damage—are predominantly natural in India, yet can also be man-made [3]. Five recurring extreme natural hazards affect India: cyclones, floods, droughts, earthquakes, and landslides [2]. India's 7,516 km coastline and vast arid and semi-arid regions underscore resultant social-environmental vulnerabilities, while plate boundaries and tectonic faults leave many regions prone to earthquakes and landslides. Given the high mortality, injuries, and damage associated with these events, disaster mitigation is crucial.

The capacity to analyze disaster characteristics and repercussions underpins mitigation efforts. Post-disaster scenarios reveal extraordinary requirements for water, food, and health aid that depend on rapid infrastructure assessments. The human toll of destroyed or incapacitated structures far exceeds that of aircraft crashes or fires of comparable scale. Timely structural damage detection, therefore, becomes imperative for prioritizing assistance and addressing potential losses—critical given limited resources.

Though instantaneous detection remains technologically unfeasible, satellite imagery provides post-mortem damage assessment. Such examinations also enhance understanding of structural vulnerability, thereby informing future safeguards to reduce losses.

Future Research Directions

Seismic structural design aims to create structures that can withstand earthquake forces, ensuring assured loads and load combinations from seismic events are considered in design [1]. Despite the availability of IS 1893 provisions for ductile detailing, buildings constructed in India frequently fail due to poor adherence to these guidelines. This is partly because many practicing engineers and construction personnel lack thorough training on earthquake-resistant design principles and detailing requirements. Consequently, research on novel building materials and structural systems capable of enhancing resilience to seismic effects is a priority.

The FEM approach offers a means to evaluate buildings with non-uniform, staggered, or asymmetric configurations and irregular distributions of structural systems [2]. Investigations into innovative materials for earthquake-resistant structures contribute to the development of effective design practices that promote life safety and property protection. Future research will also extend to socio-economic studies focusing on seismic risk and associated losses, which will inform recommendations for effective mitigation strategies and policies. Integrating advancements in engineering and socio-economic understanding provides a comprehensive pathway toward reducing earthquake hazards in the Indian context.

Innovations in Earthquake Engineering

Significant earthquakes affect structures for which destructive design is inappropriate. Stress concentrations in dynamic impact produce strains exceeding conventional yielding, leading to collapse, while proposed methods create autoadaptive designs with controllable yielding limits enhancing damage tolerance. For prevention, cost-effective solutions include seismic bases and base-isolation devices that isolate structures from earthquake shocks, effectively applied in tall buildings and critical facilities, possibly utilizing sophisticated 3D vibration-damping mechanisms for spatial isolation. Unlike the focused effort on earthquakes, flood regions receive comparatively little attention despite their hazards.

Events of widespread infrastructure damage underscore the need for economically efficient methods enabling infrastructures to withstand extreme events. Multi-hazard resistance is also necessary; for example, earthquakes induce floods post-dam failures. Studies reveal that different natural phenomena induce alternating and multi-directional displacements, posing special problems for structure safety. Specifically, earthquakes produce structural displacements absorbed by deformation modes of certain structural elements, while blast-induced displacements exceed static structural tolerances in a short time frame. Similarly, structures in flooding and severe thunder-storms must endure displacement rates at unusual levels. However, common displacement or strain modes from these phenomena permit the use of autoadaptive dynamic structures to frequent natural events.

Socio-economic Impacts of Earthquakes

Earthquakes affect population and economic infrastructure, often causing major disruption and hardship. Sully (2015) explored the Amatrice earthquake's effects on urban services in Amatrice and surrounding towns to assess the territory's preparedness and the effectiveness of the response. Fragility curves were used to estimate post-earthquake scenarios due to the facilities and services out of use. Microzonation studies by Mathur (2004) emphasize special attention to heritage/monumental buildings and lifelines such as rail/road, water supply, electric supply, sewage, communication, dams, hospitals, schools, and vulnerable industries. Safe zones and secure routes for relief centers and relief dispersion need identification during future disasters. Post-disaster resilience, prevention, and mitigation strategies require advanced planning and should constitute an integral part of the development program in potentially hazardous areas.

Existing seismic risk assessments for Nepal primarily address ground shaking, but full risk analysis requires considering hazards of landslides, liquefaction, aftershocks, and tsunamis, which can sometimes cause more damage than the initial event [5].

Conclusion

India is very prone to earthquakes, as a result of its location and the dynamics of the Indian plate and surrounding plates. The northern region including the northwest, the eastern states of Arunachal Pradesh, large parts of northeast India and the western region including the Kutch and some part of Maharashtra fall under the seismic high-risk region of the country. Earthquake can take the form of prediction at a very high level or risk-assessment, performed by different models like qualitative and quantitative models. Risk assessment is done majorly by considering three important components, namely, hazard, vulnerability and preparedness. Vulnerability changes with time as it is related to the structure. Buildings play an important role in earthquake risk reduction and they can be made earthquake resistant with the help of building codes and retrofitting techniques. Finally, good preparedness with the help of an emergency plan and strategy can help minimize the loss of life during an earthquake.

A good earthquake risk assessment is one that includes all the three factors (hazard, vulnerability and preparedness) in a uniform and effective manner, and suggests suitable solutions to reduce the risk in each region. Earthquakes are not new to the country, and several high-magnitude earthquakes as well as those with substantial numbers of casualties have already occurred. Every region falls under a different risk zone and hence the risk assessment will be different for each.

References:

1. Sitharam, T. G., Anbazhagan, P., & Vipin, K. S. (2010). Principles and practices of seismic microzonation: case studies in India.
2. Sil, A. "Seismic Hazard Assessment of Tripura and Mizoram States along with Microzonation of Agartala and Aizawl Cities." 2013.
3. Mathur, V. K. (2004). Microzonation Studies for Delhi, Jabalpur & Dehradun as Impacted by Bhuj Earthquake.
4. P. Stewart, J., E. Hough, S., Velan Vandhana, S., and Martin, S. "Damage Patterns." 2002. Earthquake spectra, 2002•journals.sagepub.com
5. R. Robinson, T., J. Rosser, N., L. Densmore, A., Oven, K., N. Shrestha, S., and Guragain, R. "Use of scenario ensembles for deriving seismic risk." 2018. Proceedings of the National Academy of Sciences 115(41):201807433
6. Zhang, Y., F. Fung, J., J. Johnson, K., and Sattar, S. "Review of Seismic Risk Mitigation Policies in Earthquake-Prone Countries: Lessons for Earthquake Resilience in the United States."
7. Brainard, C., Ladd, D., Tappen, J., Kumar, A., Vashisht, C., & Prasad, P. (2019). Integrating Earthquake Preparedness at IIT-Mandi.
8. Agarwalla, R., Pathak, R., Siddiqui, A., Panda, M., Gupta, E., & Islam, F. (2020). A community-based intervention study to assess the effectiveness of awareness imparted on earthquake preparedness among the residents of South Delhi, India. Indian journal of community medicine, 45(3), 375-378.
9. Mandal, P., Prathigadapa, R., Srinivas, D., Saha, S., & Saha, G. (2023). Evidence of structural segmentation of the Uttarakhand Himalaya and its implications for earthquake hazard. Scientific reports, 13(1), 2079.
10. Sinha, S., & Selvan, S. (2022). An improved probabilistic seismic hazard assessment of Tripura, India. Pure and Applied Geophysics, 179(12), 4371-4393.
11. Pasari, S., & Mehta, A. (2018). Nowcasting earthquakes in the northwest Himalaya and surrounding regions. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 42, 855-859.
12. George, S., & Kumar, P. A. (2022). Indicator-based assessment of capacity development for disaster preparedness in the Indian context. Environment Systems and Decisions, 42(3), 417-435.
13. McGregor, I., Yerbury, H., & Shahid, A. (2018). The voices of local NGOs in climate change issues: Examples from climate vulnerable nations. Cosmopolitan Civil Societies: An Interdisciplinary Journal, 10(3), 63-80.
14. Rival, A. (2019). Leadership for Promoting Sustainable Development: A Study of Nongovernmental Organization Leaders in Haiti. University of the Incarnate Word.
15. Gowthami, A. and Bala Gopi Krishana, K. "EFFECTIVE PERFORMANCE OF THE STEEL AND CONCRETE RC FRAME MAKING." 2016.
16. Rau, S. N., & Varma, R. K. (1981). Planning instrumentation monitoring in dams.
17. Patra, J., & Kantariya, K. (2014). Science–policy interface for disaster risk management in India: toward an enabling environment. Current Science, 39-45.