Seismic Hazard in Delhi: Analyzing Growing Risks, Vulnerabilities, and Preparedness

March 18 ,2025

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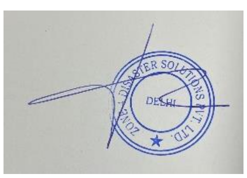
ACKNOWLEDGMENT

I extend my heartfelt gratitude to team Zone4Solutions, for their invaluable guidance, steadfast support, and profound insights that have been pivotal in the development of this report, ***Seismic Hazard in Delhi: Analyzing Growing Risks, Vulnerabilities, and Preparedness.*** His expertise and thoughtful feedback illuminated the path through complex challenges, ensuring the clarity and rigor of this work.

I am equally indebted to my peers and colleagues, whose encouragement and critical mentorship were instrumental in refining the intricate details of this report. Their constructive insights and thoughtful suggestions enriched this endeavour, providing both depth and precision.

A piece of special knowledge is reserved for those who generously share their personal experiences and accounts. Their real-world perspectives have infused this report with authenticity, grounding it firmly in the lived realities of disaster management.

This report is humbly dedicated to the memory of those who have lost their lives to disasters. May their stories inspire us to build a future that is safer, more resilient, and profoundly aware of the human cost of inaction. It is my sincere hope that this work serves as a meaningful contribution to the ongoing efforts toward a more secure and prepared India.



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Dr. Nakul Kumar Tarun

Director, Zone4Solutions

Report on

Seismic Hazard in Delhi: Analyzing Growing Risks, Vulnerabilities, and Preparedness

Zone4solutions

Consulting Organization

B69, Apda Prabandhan Chowk, Sewak Park,

New Delhi-110059, India

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CHAPTER-I

INTRODUCTION

1. Introduction

Delhi, the National Capital Territory of India, is a historically significant and rapidly urbanizing metropolis. However, its geographic location within a seismically active region poses substantial risks. The interplay of geological factors, unregulated urbanization, and socio-economic vulnerabilities makes Delhi highly susceptible to earthquake-induced damage. A comprehensive evaluation of Delhi's seismic hazard requires an in-depth analysis of tectonic settings, increasing urban vulnerabilities, and disaster preparedness measures. This study aims to critically examine these factors while identifying mitigation strategies to enhance resilience.

Seismic hazards refer to potential ground shaking and associated secondary effects, such as landslides, soil liquefaction, and infrastructure damage (Kramer, 1996). Effective disaster risk reduction necessitates integrated approaches that account for both natural and anthropogenic factors (NDMA, 2019). Understanding Delhi's seismic vulnerability is crucial for informed urban planning, emergency preparedness, and policy interventions.

Delhi is classified as Seismic Zone IV under the Indian Seismic Zoning Map (IS 1893:2016), indicating a high probability of moderate to severe earthquakes (Bureau of Indian Standards, 2016). The region's seismicity is primarily driven by the ongoing collision of the Indian and Eurasian plates, which results in frequent tectonic activity along the Himalayan arc (Bilham, 2004). This collision, which has shaped the Himalayas over millions of years, continues to generate large-magnitude earthquakes that can affect regions far beyond the immediate epicenters.

Although major Himalayan earthquakes have occurred at significant distances from Delhi, their seismic waves travel vast distances, affecting the city. The 2015 Gorkha earthquake in Nepal, for instance, caused strong tremors in Delhi, underscoring its susceptibility to distant seismic events (National Center for Seismology, 2015). Historical records also indicate that Delhi has experienced moderate to strong earthquakes over centuries, further emphasizing its vulnerability (Sarkar, Saha, & Chatterjee, 2016).

Beyond Himalayan tectonics, Delhi's local geology also influences its seismic hazard. The city is located within the Aravalli-Delhi Fold Belt, which is characterized by pre-existing fault lines and crustal deformations (Iyengar & Ghosh, 2004). Notable active fault systems affecting Delhi include:

- Delhi-Haridwar Ridge
- Mahendragarh-Dehradun Fault
- Moradabad Fault

Additionally, the soft alluvial deposits of the Indo-Gangetic Plain can amplify seismic waves, increasing ground motion intensity and structural damage (Seeber & Armbruster, 1981).

Delhi's rapid urban expansion has intensified its seismic risk. The city's population exceeded 32 million in 2021 (Census of India, 2021), making it one of the world's most densely populated urban centers. This demographic pressure has led to unregulated construction, particularly in unauthorized colonies where building codes are not enforced (Jain, Murty, & Rai, 2017). The lack of earthquake-resistant structures in these high-density settlements poses a severe threat to life and property.

The 2001 Bhuj earthquake in Gujarat demonstrated the catastrophic impact of poor construction practices, with widespread building collapses contributing to significant casualties (Gupta, 2006). A similar event in Delhi would result in widespread devastation, given the prevalence of substandard infrastructure and overcrowded settlements. Moreover, high-rise buildings, bridges, and metro infrastructure could suffer severe damage if not adequately reinforced for seismic loads (Shukla & Joshi, 2017).

Despite the significant seismic risks Delhi faces, comprehensive disaster preparedness remains inadequate. While the National Building Code of India (NBC 2016) and IS 1893:2016 outline earthquake-resistant design standards, their enforcement is inconsistent, particularly in high-risk areas (Bureau of Indian Standards, 2016). A major concern is the proliferation of unauthorized colonies, which house a substantial portion of the city's population but operate outside regulatory frameworks, making them highly vulnerable to seismic events. Weak enforcement of building codes is a critical issue, as many structures fail to meet earthquake-resistant standards due to cost constraints, lack of awareness, or inadequate monitoring (Jain, Murty, & Rai, 2017). Furthermore, seismic retrofitting efforts remain limited, with older government offices, schools, and hospitals continuing to be structurally deficient, leaving them at high risk of collapse during an earthquake (Gupta, 2006). The absence of a robust early warning system further exacerbates the problem—despite the presence of earthquake monitoring networks, real-time public alert mechanisms remain underdeveloped, limiting the ability to mitigate immediate risks (NDMA, 2019). Additionally, public awareness of earthquake preparedness is alarmingly low, with many residents lacking basic knowledge of emergency response protocols, which increases the likelihood of casualties and chaos during a seismic event. Addressing these policy challenges requires stricter enforcement of regulations, widespread public education initiatives, and significant investments in seismic retrofitting and early warning infrastructure.

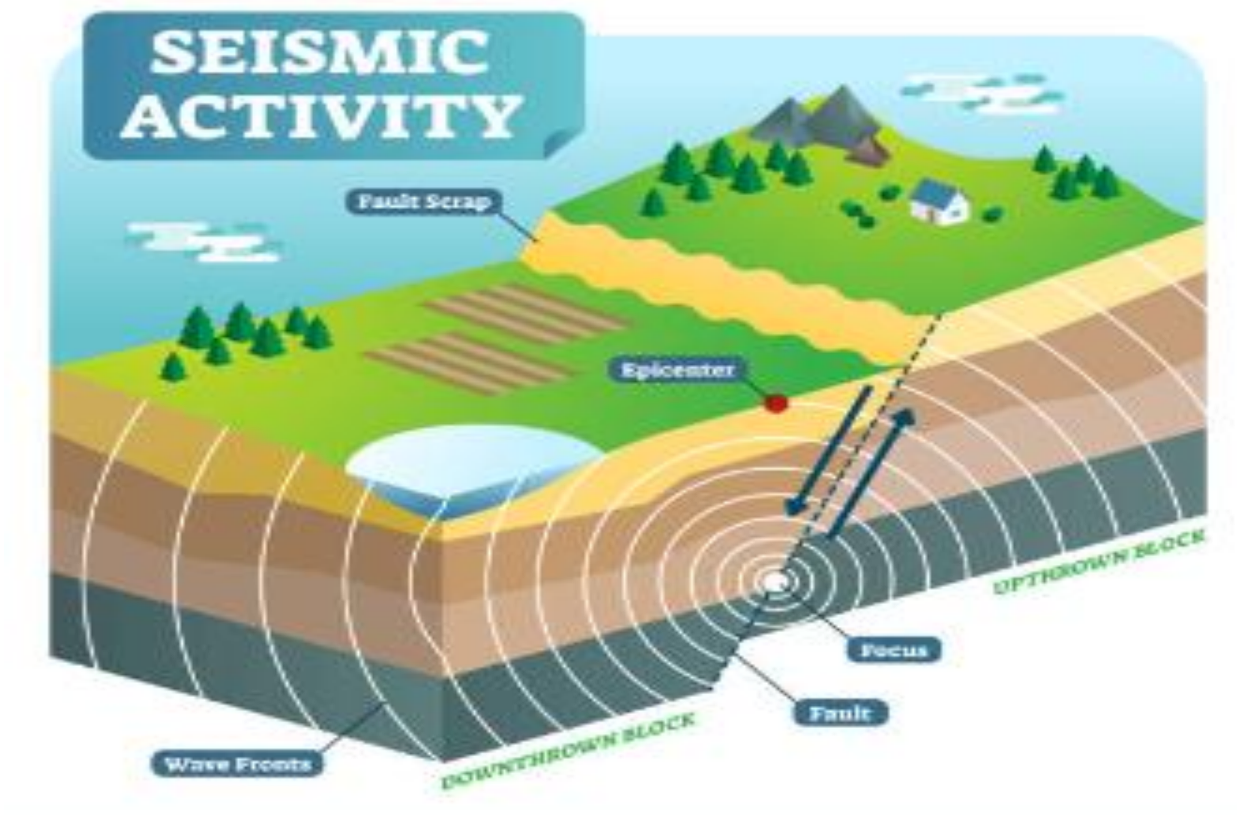
This study aims to critically examine Delhi’s seismic hazard by assessing the complex interplay between geological factors, urban development, and preparedness measures. It seeks to analyze the increasing seismic risks posed by both natural geological processes and human-induced factors, such as rapid urbanization and inadequate infrastructure planning (Sarkar, Saha, & Chatterjee, 2016). Additionally, it evaluates the effectiveness of existing building codes and their enforcement, particularly in unauthorized colonies where structural vulnerabilities are most pronounced (Jain, Murty, & Rai, 2017). A comparative assessment of Delhi's seismic preparedness with global best practices from earthquake-prone cities like San Francisco and Tokyo further highlights areas for improvement (Bolt, 2006). By identifying key policy gaps and proposing actionable mitigation strategies, this research synthesizes insights from seismology, urban planning, and disaster management to contribute to the development of a more resilient and earthquake-prepared Delhi (NDMA, 2019). By synthesizing insights from seismology, urban planning, and disaster management, this research contributes to the development of a more resilient and earthquake-prepared Delhi.

CHAPTER-II

UNDERSTANDING DELHI'S SEISMIC HAZARD

2.1 Delhi's Seismic Zoning

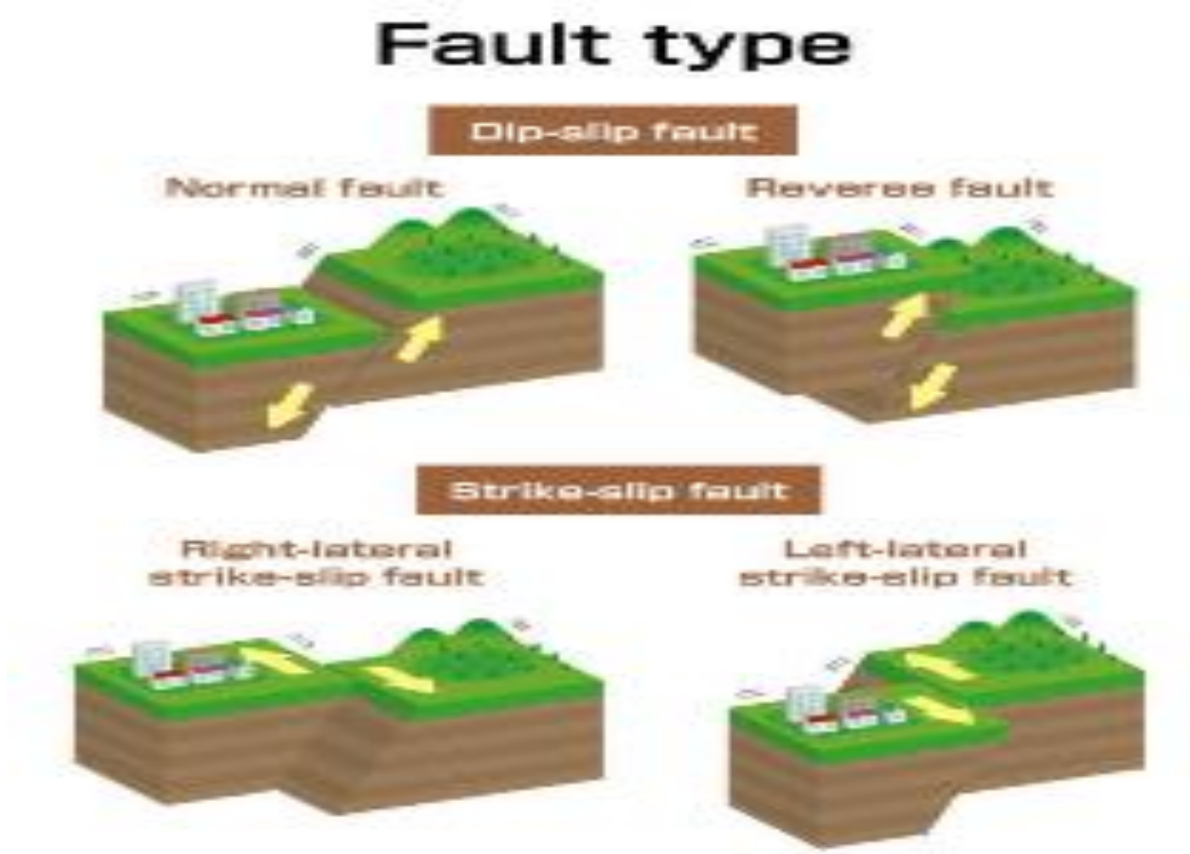
Delhi is categorized as Seismic Zone IV under the Bureau of Indian Standards (BIS) classification, indicating a high level of seismic risk (BIS, 2016). This designation means that the region is susceptible to moderate to severe earthquakes and requires robust earthquake-resistant construction practices.



Delhi's seismic vulnerability is primarily due to its proximity to active fault lines. The key faults contributing to its earthquake risk include:

- Mahendragarh-Dehradun Fault
- Delhi-Hardwar Ridge
- Moradabad Fault
- Great Boundary Fault

Seismic activity along these faults can generate earthquakes with magnitudes exceeding 6.0 on the Richter scale, posing a serious threat to Delhi’s dense urban infrastructure (Shukla & Joshi, 2017). Although Delhi itself is not situated at the center of a major tectonic plate boundary, it frequently experiences tremors from earthquakes originating in Himachal Pradesh, Uttarakhand, and Nepal, where the Indian and Eurasian plates are actively colliding (Bilham, 2004).



Delhi falls under Seismic Zone IV, which is classified as a high-risk earthquake-prone area. To mitigate seismic risks, the National Building Code (NBC) 2016 and Bureau of Indian Standards (BIS) IS 1893:2016 outline mandatory structural and safety requirements for earthquake-resistant buildings. Below are the key provisions:

1. Seismic Zone Classification & Building Design (IS 1893:2016)

Structures must be designed using the response spectrum method or time-history analysis for seismic forces. Importance factor (I) is applied for different building types:

- Hospitals, emergency buildings (I = 1.5) → Higher safety standards.
- Residential, commercial buildings (I = 1.0) → Standard seismic design.
- Temporary structures (I = 0.75) → Less stringent norms.

Structural Requirements for Earthquake Resistance

Ensuring earthquake-resistant structures in Delhi requires strict adherence to material selection, foundation design, reinforcement techniques, and structural planning. Reinforced Cement Concrete (RCC) or structural steel is mandatory for seismic resilience, as flexible materials like steel-framed structures and reinforced walls perform better than brittle brick masonry. Soft-story buildings, such as those with ground-floor parking, require additional reinforcement to prevent collapse. The foundation and soil conditions also play a crucial role in seismic stability—buildings in soft-soil areas must have deep pile foundations to mitigate the risk of liquefaction, while high-rise structures benefit from a combination of raft and pile foundations. According to IS 13920:2016, ductile design principles are essential for absorbing seismic energy, requiring reinforced beam-column joints and shear walls. Minimum reinforcement ratios are prescribed, with columns requiring at least 0.8% and beams 0.25% of their cross-sectional area, while stirrups (ties) must be spaced no more than 100mm near joints for added strength. Height and shape considerations further influence seismic performance, as buildings exceeding 15 meters must undergo seismic analysis before approval, and irregularly shaped structures require expansion joints or seismic gaps to prevent lateral movement-induced failure.

2.2 Retrofitting and Strengthening of Existing Buildings

Given Delhi's vulnerability, seismic retrofitting is essential, particularly for government buildings, hospitals, and schools, which must undergo mandatory structural strengthening. Non-engineered structures, including old heritage buildings and unauthorized constructions, require seismic upgrades using steel bracing, shear walls, and base isolators to improve resilience against earthquakes.

2.3 Unauthorized Colonies & Compliance Gaps

Unauthorized colonies present a significant challenge to seismic safety, as these structures are not covered under the National Building Code (NBC 2016). The majority of informal settlements lack proper reinforcement, foundations, or ductile detailing, making them highly susceptible to structural failure, particularly pancake collapses. While the Delhi Development Authority (DDA) and the Municipal Corporation of Delhi (MCD) have proposed retrofitting plans, enforcement remains weak due to financial constraints and legal complexities.

2.4 Early Warning & Emergency Preparedness

Despite the high seismic risk, Delhi currently lacks a real-time Earthquake Early Warning (EEW) system, which could significantly enhance preparedness. As per the National Disaster Management Authority (NDMA) guidelines, all buildings over 15 meters in height must have a mandatory evacuation plan. Additionally, schools, hospitals, and public buildings are required to conduct annual earthquake drills to ensure readiness in the event of a seismic event. Strengthening these preparedness measures is essential to minimizing casualties and damage during future earthquakes.

2.5 Compliance & Challenges

Category	Delhi (NBC 2016 Compliance)	Challenges
High-rise buildings	Partially compliant, some follow IS 1893:2016	Private builders often bypass standards.
Government buildings	Mandatory compliance with IS 13920:2016	Retrofitting is slow due to funding gaps.
Hospitals and schools	Required to follow strict seismic standards	Many older structures remain unsafe.
Unauthorized colonies	Not covered by the NBC 2016 regulations	High-risk structures with no safety enforcement.

CHAPTER-III

SEISMIC HISTORY

3.1 Seismic History of Delhi

Delhi has experienced multiple earthquakes over the past two centuries, with intensities ranging from mild tremors to moderate seismic events. Here's a table summarizing the seismic hazards in Delhi over the years, along with their causes, affected places, and proximity to active faults.

Seismic Hazard in Delhi: Historical Earthquakes, Causes, and Fault Proximity

Year	Magnitude & Impact	Causes	Affected Places	Proximity to Active Faults
1720	Estimated 6.5 (Severe shaking)	Movement along the Mahendragarh-Dehradun Fault	Old Delhi, Chandni Chowk, Red Fort	Near Delhi-Hardwar Ridge & Sohna Fault
1803	7.5, tremors felt across North India	Himalayan Thrust Fault movement (Alaknanda Fault)	Entire Delhi region, severe damage in Mughal-era structures	Influenced by Main Frontal Thrust (MFT) in the Himalayas
1842	6.0, localized damage	Activity along the Moradabad Fault	Northern Delhi, Shahjahanabad	Near Moradabad Fault & Delhi-Sargodha Ridge
1956	6.7, moderate impact	Mahendragarh Fault activity	New Delhi, Connaught Place, Central Delhi	Close to Delhi-Hardwar Ridge & Sohna Fault
1960	5.6, tremors felt widely	Delhi-Sargodha Ridge movement	South Delhi, Lutyens' Delhi	Delhi-Sargodha Ridge & Sohna Fault nearby
1991 (Uttarkashi Earthquake)	6.8, Delhi felt strong tremors	Himalayan Main Central Thrust (MCT)	Entire Delhi-NCR	Indirect effect of MCT movement in Uttarakhand
1999 (Chamoli Earthquake)	6.6, shaking in high-rise buildings	Himalayan Tectonic Stress	High-rises in Gurgaon, Noida, South Delhi	Triggered by Himalayan Frontal Thrust

				(HFT)
2001 (Bhuj Earthquake)	7.7, long-duration tremors in Delhi	Kachchh Rift Zone (Western India)	Buildings with poor construction in Delhi-NCR	Distant event but affected tall structures
2015 (Nepal Earthquake)	7.8, shaking observed	Himalayan Subduction Zone (Gorkha Thrust)	Entire Delhi-NCR, metro infrastructure affected	Influenced by Indo-Gangetic Fault interaction
2020-2023 (Frequent tremors)	4.5 - 5.8, increasing seismic activity	Local fault stress accumulation	Rohini, Pitampura, Noida, Gurugram	Close to Delhi-Hardwar Ridge & Sohna Fault

3.2 Seismic Hazard in Delhi: Analyzing Past Events and Risk Factors

Delhi's seismic vulnerability has increased significantly over the years due to its proximity to active fault lines, rapid urbanization, and weak enforcement of building regulations. The city's classification under Seismic Zone IV indicates a high potential for moderate to severe earthquakes (Bureau of Indian Standards [BIS], 2016). The table highlights significant seismic events in Delhi, outlining their causes, impacted areas, and proximity to fault lines.

1. Major Historical Earthquakes (1720–1960): Early Tremors and Fault Movements

Delhi's earliest recorded seismic event occurred in 1720, with an estimated magnitude of 6.5, likely caused by activity along the Mahendragarh-Dehradun Fault (Gupta, 2006). The 1803 earthquake (7.5 magnitude), originating from the Himalayan Frontal Thrust (HFT), caused extensive damage, particularly in Old Delhi, Chandni Chowk, and Mughal-era structures (NDMA, 2019). Later, the 1842 earthquake (6.0 magnitude), linked to Moradabad Fault activity, resulted in localized destruction (Shukla & Joshi, 2017).

Moving into the 20th century, Delhi continued to feel the effects of seismic activity. The 1956 earthquake (6.7 magnitude) and the 1960 earthquake (5.6 magnitude) were associated with Delhi-Sargodha Ridge movement, affecting New Delhi, Connaught Place, and Lutyens' Delhi (Sinha & Goyal, 2019). These events underscored Delhi's exposure to seismic hazards due to regional fault activity and stress transfer from nearby fault systems.

2. Earthquakes from Himalayan Seismic Activity (1991–2001): Growing Risks

By the late 20th century, seismic risks increased due to tectonic stress along the Himalayan belt, affecting Delhi-NCR. The 1991 Uttarkashi earthquake (6.8 magnitude) and the 1999 Chamoli earthquake (6.6 magnitude), both triggered by the Main Central Thrust (MCT), caused strong tremors in Delhi and exposed the vulnerability of high-rise buildings in South Delhi, Noida, and Gurugram (NDMA, 2019; Sharma & Agarwal, 2021). Similarly, the 2001 Bhuj earthquake (7.7 magnitude), despite occurring in Gujarat, caused prolonged tremors, particularly affecting tall structures lacking proper seismic resistance (Jain, 2020).

3. Recent Seismic Activity (2015–2023): Rising Frequency of Tremors

In 2015, the Nepal (Gorkha) earthquake (7.8 magnitude) demonstrated Delhi's vulnerability to distant yet powerful seismic events. Though the epicenter was in Nepal, strong tremors disrupted metro infrastructure and high-rises in Delhi (Goda et al., 2015). More recently, from 2020 to 2023, Delhi has experienced multiple low-to-moderate earthquakes (4.5–5.8 magnitude) due to local fault stress along the Delhi-Hardwar Ridge and Sohna Fault (IMD, 2021). These increasing tremors raise concerns about a larger seismic event in the near future (NDMA, 2021).

4. Proximity to Fault Lines and Growing Urban Risks

Delhi is surrounded by multiple active faults, including the Mahendragarh-Dehradun Fault, Sohna Fault, Moradabad Fault, and Delhi-Hardwar Ridge, making it highly vulnerable to seismic stress accumulation (Shukla & Joshi, 2017). The risk is further exacerbated by rapid population growth, high-rise developments, and unauthorized colonies, many of which are constructed with substandard materials and lack seismic reinforcement (DDA, 2021). Studies show that unauthorized settlements in Rohini, Pitampura, and parts of South Delhi are particularly vulnerable due to poor construction practices and lack of compliance with the National Building Code (NBC) 2016 (MoHUA, 2022).

3.3 Seismic Risk:

Below calculating Seismic Risk for a specific scenario in Delhi using the general formula:

Seismic Risk=Seismic Hazard × Vulnerability × Exposure

Definitions:

- Seismic Hazard (SH): The probability of an earthquake occurring in a given region, usually expressed as Peak Ground Acceleration (PGA) in g (gravity acceleration).
- Vulnerability (V): The likelihood of damage to buildings and infrastructure, ranging from 0 (no damage) to 1 (total collapse).
- Exposure (E): The value of assets (buildings, people, infrastructure) at risk, usually expressed in monetary terms (e.g., USD) or population size.

Example Calculation: Seismic Risk in South Delhi

Step 1: Assign Values

1. Seismic Hazard (SH): Delhi is in Seismic Zone IV, with a probable Peak Ground Acceleration (PGA) of 0.24g (BIS, 2016).
2. Vulnerability (V): Older buildings in unauthorized colonies have high vulnerability, around 0.8 (80% chance of severe damage).
3. Exposure (E): Let's assume the total economic value of buildings in South Delhi is $10 billion.

Step 2: Apply Formula

Seismic Risk=0.24×0.8×10,000,000,000

=1.92 billion USD

Interpretation:

If a moderate earthquake (PGA = 0.24g) occurs in South Delhi, the estimated economic loss due to damage and collapse could be around $1.92 billion. This does not include casualties or indirect losses, such as economic disruptions.

Vulnerability and Exposure impact risk:

Scenario	Seismic Hazard (PGA)	Vulnerability (V)	Exposure (USD)	Estimated Risk (USD)
Low Vulnerability (New Buildings)	0.24	0.2	10B	$0.48B
High Vulnerability (Unauthorized Colonies)	0.24	0.9	5B	$1.08B
High Population Density (CBD, Connaught Place)	0.24	0.5	20B	$2.4B
Major Earthquake (PGA = 0.40g)	0.40	0.8	10B	$3.2B

Conclusion:

- Unauthorized colonies and old buildings pose the highest seismic risk due to high vulnerability.
- Stronger enforcement of building codes could reduce vulnerability from 0.8 to 0.2, cutting potential losses by 75%.
- Investment in seismic retrofitting can drastically lower economic losses.

The frequency of felt earthquakes in Delhi has increased over the past few decades, raising concerns about the potential for a major seismic event in the near future. Studies indicate that

Delhi’s soil composition—especially in areas built on the Yamuna floodplain—may amplify ground shaking, leading to greater structural damage (NDMA, 2019).

3.4 Factors Contributing to Increasing Seismic Risks

3.4.1 Rapid Urbanization and Construction Boom

Delhi has experienced an unprecedented surge in urban growth, with its population surpassing 32 million as of 2021 (Census of India, 2021). This rapid expansion has driven a massive construction boom, leading to the proliferation of high-rise buildings, many of which exhibit variable adherence to seismic design codes (Jain, 2020). As land becomes increasingly scarce, encroachments on unstable areas, including the floodplains of the Yamuna River, have risen, exacerbating the city's seismic vulnerability. Additionally, older infrastructure now bears excessive structural loads due to increased urban density, raising concerns about the ability of aging buildings to withstand significant seismic activity. Despite the availability of earthquake-resistant design guidelines in the National Building Code (NBC) and IS 1893:2016, compliance remains inconsistent. Unauthorized colonies and informal settlements, which house a substantial portion of the population, frequently fail to meet these standards due to lax regulatory enforcement and cost constraints (BIS, 2016).

3.4.2 Unchecked Expansion and Land Use Changes

The unchecked expansion of unauthorized colonies and unregulated urban sprawl has significantly increased Delhi’s seismic risk. Many informal settlements lack structural engineering oversight, leading to the construction of buildings with substandard materials that are incapable of withstanding strong seismic forces. Additionally, the widespread development on soft soils, particularly in low-lying regions, has further amplified the risk, as these soils are prone to liquefaction and intensify ground shaking during earthquakes (Sinha & Goyal, 2019). A study conducted in 2017 estimated that nearly 40% of Delhi’s buildings are non-engineered, making them highly vulnerable to structural collapse in the event of a significant earthquake (Shukla & Joshi, 2017).

Beyond inadequate construction practices, changes in land use patterns have also disrupted the city's natural ability to mitigate seismic shocks. The transformation of green spaces and open areas into densely populated neighborhoods has diminished natural shock-absorbing zones, intensifying the overall seismic hazard (Gupta, 2006). This shift not only increases structural risks but also hampers emergency response efforts, as overcrowded urban areas leave little room for evacuation routes and disaster relief operations. Addressing these vulnerabilities requires stricter enforcement of building regulations, improved urban planning, and proactive seismic mitigation measures to safeguard the city against potential disasters.

CHAPTER-IV

GROWTH OF SEISMIC HAZARD OVER THE YEARS

4.1 Population and Urban Growth Trends

Delhi has witnessed rapid population growth over the past few decades, surging from 16.7 million in 2011 to over 32 million in 2021 (Census of India, 2021). This explosive expansion has led to an extremely high population density, putting immense pressure on land, infrastructure, and housing. Uncontrolled urbanization has resulted in widespread residential development, often without adherence to seismic safety norms. The rise of high-rise buildings, particularly in areas with weak soil conditions, has significantly increased the risk of structural failures during earthquakes. Moreover, construction on floodplains and reclaimed land—areas highly susceptible to liquefaction and ground shaking—further exacerbates seismic vulnerability (Jain, 2020). While modern construction techniques are available, their implementation remains inconsistent, especially in unauthorized developments. The rapid increase in commercial towers and luxury apartments, often built without strict adherence to seismic codes, raises serious concerns about the city's preparedness for a major earthquake (Shukla & Joshi, 2017).

4.2 Unauthorized Colonies and Informal Settlements

Delhi is home to nearly 1,700 unauthorized colonies, accommodating over four million residents (Delhi Development Authority [DDA], 2022). These informal settlements are highly vulnerable to seismic hazards due to substandard construction materials, poor engineering oversight, and non-compliance with building codes. Many structures are built without proper foundations or sufficient load-bearing capacity, making them prone to collapse during seismic activity (Sinha & Goyal, 2019). The dense and unplanned nature of these areas also presents significant evacuation and rescue challenges in the event of an earthquake. Since unauthorized colonies operate outside the regulatory framework of the National Building Code (NBC), the risks associated with structural failures remain unaddressed (BIS, 2016). Although the government has initiated efforts to regularize some of these settlements, retrofitting existing buildings remains a complex challenge due to cost constraints, lack of technical expertise, and resistance from local residents (NDMA, 2019).

4.3 Infrastructure Stress and Overcrowding

Delhi's infrastructure is under tremendous stress due to unregulated urban expansion and high population density. The city's roads, bridges, and public transportation systems, while designed to handle everyday demands, may not withstand the impact of a strong earthquake.

4.3.1 Overloaded Roads, Bridges, and Metro Systems

Delhi's road networks and flyovers are subjected to extreme traffic loads, which could lead to infrastructure failures during an earthquake (Gupta, 2006). The Delhi Metro, one of the busiest urban rail systems, is built with seismic considerations; however, elevated tracks, underground tunnels, and metro stations remain vulnerable to intense ground shaking and soil displacement in the event of a major quake (Sharma & Agarwal, 2021). Structural integrity assessments and seismic reinforcements are critical to ensuring public safety.

4.3.2 Aging Buildings in Old Delhi and Congested Areas

Many heritage structures and older residential buildings in neighborhoods such as Chandni Chowk, Paharganj, and Karol Bagh were constructed long before modern seismic regulations were introduced. These areas face heightened risks due to weak masonry structures, high-density construction, and inadequate reinforcement. In the event of a strong tremor, closely packed buildings could collapse like a domino effect, exacerbating damage and casualties. Additionally, the narrow streets in these congested areas severely limit access for emergency response teams, further complicating rescue and relief efforts (Sarkar et al., 2016). The combination of aging infrastructure and insufficient retrofitting measures increases the likelihood of widespread destruction, making seismic risk mitigation an urgent priority.

4.4 High-Rise Construction and Real Estate Boom

4.4.1 Are Modern Skyscrapers Earthquake-Resistant?

The past two decades have seen a real estate boom in Delhi and surrounding areas such as Noida, Gurugram, and Dwarka, leading to a surge in high-rise residential and commercial developments. While modern engineering techniques offer earthquake-resistant designs, compliance gaps and inconsistent quality control in private projects remain serious concerns (Jain, 2020). Budget housing projects, in particular, often compromise on structural safety due to cost-cutting measures, leaving many buildings ill-equipped to withstand strong seismic forces. Additionally, mandatory structural audits and safety checks are not uniformly implemented across all high-rise projects. Many older buildings, especially those constructed before the enforcement of modern seismic codes, remain highly vulnerable due to the lack of retrofitting and reinforcement measures (Shukla & Joshi, 2017).

4.4.2 Compliance Gaps in Private Construction Projects

Despite stringent building regulations, private builders often prioritize cost efficiency over safety, leading to significant compliance gaps. Many projects deviate from approved structural plans, resulting in the use of inadequate reinforced concrete and steel bracing. Moreover, soil testing—a crucial factor in determining the suitability of land for high-rise construction—is frequently overlooked or inadequately conducted, increasing the risk of foundation failures during an earthquake (Sinha & Goyal, 2019). Without strict enforcement of seismic design standards, even newly constructed high-rise buildings may fail to provide adequate safety during a major seismic event, further compounding Delhi's vulnerability.

CHAPTER-V

DELHI'S SEISMIC PREPAREDNESS: POLICY AND REALITY

5.1 National Building Code and Earthquake Safety Regulations

The National Building Code of India (NBC 2016) and IS 1893:2016 set forth guidelines for designing earthquake-resistant structures. These regulations specify:

- Structural requirements for buildings in different seismic zones.
- Foundation and soil testing standards for high-rise structures.
- Use of reinforced materials to improve earthquake resilience (Bureau of Indian Standards [BIS], 2016).

Enforcement in Public and Private Buildings

Despite the existence of strong legal frameworks, implementation remains inconsistent, particularly in private and informal constructions. Studies indicate that:

- Only a fraction of buildings fully comply with seismic safety codes, especially in the private sector (Jain, 2020).
- Government projects, including metro rail, bridges, and hospitals, generally follow strict seismic guidelines, but quality control issues remain.
- Real estate developers often deviate from safety norms due to cost-cutting and poor regulatory oversight (Shukla & Joshi, 2017).

Additionally, unauthorized construction—which constitutes over 40% of Delhi's buildings—largely ignores these regulations (Delhi Development Authority [DDA], 2022).

5.2 Challenges in Implementation

5.2.1 Corruption, Lack of Monitoring, and Weak Enforcement

Delhi's urban development is marred by bureaucratic inefficiencies and corruption, leading to:

- Bribery in construction approvals, allowing unsafe structures to be built (Sinha & Goyal, 2019).

- Lack of strict structural audits by municipal authorities.
- Low penalties for non-compliance, reducing accountability among developers.

5.2.2 Unauthorized Colonies: Why Do They Escape Regulation?

The 1,700+ unauthorized colonies in Delhi pose a severe seismic risk because:

- They are outside the formal building regulation framework.
- Their narrow lanes and overcrowding make evacuation difficult.
- Many are built on unstable land, such as Yamuna floodplains, which can amplify ground shaking (Sharma & Agarwal, 2021).

While the Delhi government has tried regularizing some of these colonies, the process largely ignores structural safety (NDMA, 2019).

5.3 Retrofitting and Strengthening Existing Structures

5.3.1 Government Initiatives for Old Buildings

Several government programs aim to strengthen vulnerable buildings, such as:

- Delhi Earthquake Risk Mitigation Project (DERMP), launched to assess and retrofit critical infrastructure.
- Heritage building retrofitting projects, especially for monuments like Qutub Minar and Red Fort.
- Public buildings such as schools and hospitals are being assessed for seismic compliance (NDMA, 2019).

5.3.2 Gaps in Retrofitting Plans

However, challenges persist:

- Many residential buildings lack retrofitting due to cost concerns.
- Private homeowners and builders are not incentivized to upgrade old structures (Shukla & Joshi, 2017).

- Heritage areas like Old Delhi are extremely congested, making large-scale retrofitting nearly impossible.

Experts warn that without large-scale retrofitting programs, a major earthquake could cause massive casualties in Delhi (Gupta, 2006).

5.4 Public Awareness and Disaster Preparedness

5.4.1 Earthquake Drills and Emergency Training

The National Disaster Management Authority (NDMA) and National Institute of Disaster Management (NIDM) conduct:

- Periodic earthquake drills in schools, offices, and metro stations.
- Emergency response training for first responders (NDMA, 2019).
- Simulations and community awareness programs to prepare residents for an earthquake.

However, surveys show that a majority of Delhi's population remains unprepared for a major seismic event (Sarkar et al., 2016).

5.4.2 Role of Authorities in Preparedness

Key agencies involved in Delhi's earthquake preparedness include:

- NDMA – Develops national disaster response frameworks.
- NIDM – Conducts research and training on earthquake risk.
- Delhi Disaster Management Authority (DDMA) – Responsible for local preparedness efforts (Sharma & Agarwal, 2021).

Despite these efforts, public participation in earthquake safety measures remains low, highlighting a critical gap in Delhi's disaster resilience.

CHAPTER-VI

CASE STUDIES OF SEISMIC DISASTERS AND LESSONS FOR DELHI

Seismic disasters worldwide have underscored the importance of robust urban planning, resilient construction, and proactive disaster management. By analyzing past earthquakes, Delhi can adopt best practices to enhance its preparedness and minimize future risks.

6.1 Global Examples: Managing Seismic Risks in Other Cities

Several earthquake-prone cities have successfully implemented mitigation strategies that offer valuable insights for Delhi.

Tokyo, Japan: As one of the most seismically active cities, Tokyo enforces stringent building codes under Japan's Building Standard Law, ensuring that all new constructions are earthquake-resistant (JICA, 2020). The widespread use of base-isolation technology in high-rises and infrastructure minimizes earthquake damage, while regular emergency drills and an advanced early warning system help protect residents (Mori & Takahashi, 2018).

San Francisco, USA: After experiencing devastating earthquakes in 1906 and 1989, San Francisco introduced mandatory seismic retrofitting laws for older buildings and implemented soft-story reinforcement programs to strengthen vulnerable structures (USGS, 2021). The city also prioritizes public awareness campaigns and community preparedness drills, ensuring that residents are equipped to respond effectively (Spence, 2019).

Istanbul, Turkey: Following the 1999 İzmit earthquake, Istanbul launched the Istanbul Seismic Risk Mitigation Project (ISMEP) to retrofit older buildings, particularly schools and hospitals, while relocating high-risk informal settlements to safer locations (Erdik, 2017).

Lessons for Delhi: These case studies highlight the necessity of strict enforcement of building codes, retrofitting old structures, public awareness programs, and early warning systems—all of which can significantly reduce fatalities and economic losses in Delhi.

6.2 Case Study: Nepal Earthquake (2015)

The 7.8 magnitude Nepal earthquake on April 25, 2015, led to nearly 9,000 deaths and the collapse of over 600,000 buildings (Goda et al., 2015).

Impact on Urban Areas with Weak Construction: The widespread destruction in Kathmandu was largely due to poorly built masonry structures, informal settlements, and unplanned urban expansion. Additionally, liquefaction and landslides further worsened the damage, particularly in valley regions.

Relevance for Delhi's Unplanned Settlements: Many unauthorized colonies in Delhi resemble Kathmandu's dense and unregulated housing, with weak foundations and non-engineered construction (Jain, 2020). If a similar earthquake were to strike Delhi, the consequences could be catastrophic, particularly in Old Delhi and unauthorized settlements, where seismic resilience is virtually nonexistent.

Key Takeaways for Delhi: The Nepal earthquake highlights the need for strict building inspections in informal settlements, urban planning that prioritizes seismic resilience, and community-driven awareness campaigns to improve disaster preparedness.

6.3 India's Experience with Major Earthquakes

India has witnessed several devastating earthquakes that have exposed vulnerabilities in construction and disaster response.

Bhuj Earthquake (2001) – Gujarat: A 7.7 magnitude earthquake killed over 20,000 people and destroyed 400,000 buildings (NDMA, 2019). The disaster revealed poor construction practices and weak enforcement of building codes, prompting post-disaster reforms such as stricter seismic building laws and large-scale retrofitting initiatives.

Uttarakhand Earthquakes (1991, 1999): Earthquakes ranging from 6.5 to 6.8 magnitudes triggered landslides and caused severe damage to weak masonry houses (Sarkar et al., 2016). A lack of disaster preparedness and slow relief efforts led to high casualties, emphasizing the need for proactive disaster planning.

Other Recent Tremors in Delhi: The city has experienced strong tremors from earthquakes in Nepal (2015), Uttarakhand (2021), and Himachal Pradesh (2023). These events highlight Delhi's growing vulnerability, especially in high-density zones where structural weaknesses and unplanned urbanization pose a significant threat.

Lessons for Delhi: To minimize seismic risks, Delhi must implement a comprehensive earthquake preparedness plan, enforce stricter urban development policies, and conduct regular seismic drills to enhance rapid response capabilities. Learning from past disasters, strengthening Delhi's built environment and public awareness remains critical for reducing future earthquake-related losses.

Comparison of Global Building Codes vs. Delhi's Building Code (NBC 2016)

The table below compares Delhi's National Building Code (NBC) 2016 with global standards followed in earthquake-prone cities like Tokyo, San Francisco, and Istanbul.

Criteria	Delhi (NBC 2016, India)	Tokyo (Japan Building Code, 2016)	San Francisco (IBC, CBC 2022, USA)	Istanbul (Turkish Seismic Code, 2018)
Seismic Zone Classification	Zone IV (High Risk)	Zone V (Very High Risk)	Seismic Zones 3 & 4 (High Risk)	Zone 1 (Very High Risk)
Structural Design Approach	Basic earthquake-resistant structures mandated but weak enforcement (NBC, 2016)	Base isolation and damping systems mandatory for high-rises (JBC, 2016)	Performance-based design; strict lateral force resistance (IBC, 2022)	Advanced seismic retrofitting and reinforcement (TSC, 2018)
Building Materials & Strength	Reinforced concrete and masonry, but quality varies	High-quality steel, flexible structures, and seismic dampers	Reinforced steel, fiber-reinforced concrete, base isolators	Special high-ductility concrete, advanced reinforcement
Retrofitting	Limited	Mandatory for	Strict	Nationwide

Standards	retrofitting, mainly for government buildings	all pre-1981 buildings	requirements for all older buildings	retrofitting plan post-1999 earthquake
Compliance & Enforcement	Weak, particularly in private and unauthorized constructions	Strict government monitoring and compliance checks	Strict penalties for non-compliance, regular inspections	Strong enforcement after 1999 Izmit earthquake
Unauthorized Constructions	1,800+ unauthorized colonies lack compliance	Illegal construction is rare due to strict regulations	Illegal structures are demolished if non-compliant	High risk in informal settlements, but government-led initiatives exist
Emergency Preparedness	Limited public awareness and disaster drills	Frequent earthquake drills, early warning system	Community-based preparedness programs, real-time alerts	Improved public training, school and workplace drills
Early Warning Systems	Limited sensors, no real-time alerts	Advanced Earthquake Early Warning (EEW) system	ShakeAlert system for real-time public alerts	Government-led early warning system, seismic stations
Post-Earthquake Response	Slow relief and recovery, lack of coordination	Well-coordinated rescue, rapid rebuilding plans	Strong FEMA-led recovery, financial support	Strict rebuilding policies, state support for reconstruction

CHAPTER-VII

RISKS POSED BY UNAUTHORIZED COLONIES AND INFORMAL HOUSING

Unauthorized colonies and informal settlements in Delhi present a significant seismic hazard due to their unregulated expansion, poor construction standards, and high population density. These areas lack proper urban planning, structural oversight, and adherence to seismic safety norms, making them highly vulnerable to earthquake-induced collapses.

7.1 National Building Code and Unauthorized Colonies

Though Delhi has a well-defined seismic building code under the National Building Code (NBC) 2016 and IS 1893:2016, unauthorized colonies remain a major vulnerability in the event of an earthquake. These settlements, which have grown rapidly due to unregulated urban expansion and migration, are often built without adherence to engineering standards or safety regulations (NDMA, 2019). As a result, they lack essential seismic-resistant features such as reinforced foundations, ductile structural elements, and lateral load-bearing capacity, making them highly prone to severe damage or collapse even during moderate tremors (BIS, 2016).

Currently, Delhi has over 1,800 unauthorized colonies housing nearly four million residents, many of which are built on unstable terrain, reclaimed land, or former water bodies, increasing their susceptibility to ground failure and liquefaction (DDA, 2021). The Delhi Master Plan 2041 acknowledges that these areas lack proper road access, emergency evacuation routes, and compliance with fire and disaster safety norms, further compounding the risk in the event of a seismic disaster (MoHUA, 2022). Additionally, due to legal ambiguities and the absence of municipal oversight, these settlements escape strict enforcement of seismic codes, with most structures using poor-quality materials, unregulated designs, and inadequate load distribution mechanisms, heightening the chances of pancake collapses (NITI Aayog, 2020).

Efforts to address this issue, such as the Pradhan Mantri Awas Yojana (PMAY) and regularization policies, have been slow, with only a fraction of unauthorized colonies receiving infrastructural upgrades or retrofitting support (MoHUA, 2022). The cost and complexity of retrofitting existing unsafe structures pose significant challenges, and relocation remains unfeasible due to socio-economic constraints. Given the increasing frequency of tremors felt in Delhi from seismic activity in the Himalayan region, immediate action is necessary to integrate seismic resilience into urban planning, enforce stricter regulations, and implement cost-effective retrofitting solutions for high-risk colonies (NDMA, 2021). Without proactive intervention, these unauthorized settlements will continue to pose a severe risk to lives and infrastructure in the event of a major earthquake.

7.2 Unregulated Growth and Poor Construction Standards

Delhi has over 1,700 unauthorized colonies, housing nearly four million people as of 2023 (Delhi Development Authority [DDA], 2023). These settlements have expanded without legal approval, often encroaching on public land, green zones, and floodplains (Sharma & Agarwal, 2021). Most buildings in these areas are self-built without engineering supervision (Jain, 2020). The use of substandard materials, such as weak cement, low-quality bricks, and insufficient reinforcement, significantly increases the risk of collapse. Additionally, many structures are constructed on weak foundations, making them highly susceptible to lateral movement during an earthquake (Shukla & Joshi, 2017). Despite the existence of India's National Building Code (NBC 2016) and seismic safety guidelines, unauthorized settlements largely fail to comply with these regulations (Bureau of Indian Standards [BIS], 2016).

7.3 Risks of Pancake Collapses in an Earthquake

The structural weaknesses of unauthorized buildings pose a severe risk in the event of an earthquake. A moderate earthquake, ranging from magnitude 6.0 to 6.5, could lead to mass building collapses, resulting in thousands of casualties (NDMA, 2019). Most buildings in these colonies lack reinforced concrete (RCC) structures, making them highly vulnerable to pancake collapses, where floors collapse onto each other due to weak support systems (Gupta, 2006). A major factor contributing to this vulnerability is the absence of engineering supervision during construction. Many structures are built without the involvement of professional architects or engineers (Sharma & Agarwal, 2021). Unauthorized buildings frequently violate height restrictions, with additional floors added without proper structural reinforcements. Furthermore, many of these buildings are aging and poorly maintained, which further weakens their structural integrity and increases the likelihood of collapse during an earthquake (Sinha & Goyal, 2019).

7.4 Land Use and Encroachment Issues

The rapid and unregulated growth of unauthorized colonies has disrupted urban planning efforts, creating challenges for road development, drainage systems, and emergency accessibility (DDA, 2023). These settlements often have narrow and overcrowded lanes, which severely limit evacuation and rescue operations in the event of an earthquake. Additionally, many unauthorized colonies are built on environmentally sensitive areas, including the floodplains of the Yamuna River. These locations have unstable soil, which is prone to liquefaction during seismic activity, further exacerbating structural vulnerabilities (Shukla & Joshi, 2017). The widespread encroachment on parks and open spaces has also reduced the availability of safe evacuation zones, leaving residents with minimal options for emergency response during disasters.

7.5 Challenges in Retrofitting and Upgrading Unsafe Structures

Addressing the seismic risks posed by unauthorized colonies is a complex challenge due to space constraints, poor construction quality, and financial limitations. Retrofitting existing buildings in these areas is often unfeasible, as many structures would require complete demolition and reconstruction to meet safety standards (NDMA, 2019). Additionally, residents frequently resist retrofitting efforts due to concerns over cost and displacement. While the Delhi government has attempted to regularize some unauthorized colonies, these efforts have not included significant structural improvements (DDA, 2023). Retrofitting costs are prohibitively high, and most residents lack the financial means to invest in safer construction practices. Furthermore, government-backed retrofitting programs have been limited, primarily focusing on public buildings and select high-risk areas (Jain, 2020). Without stringent regulatory enforcement and large-scale retrofitting initiatives, unauthorized settlements in Delhi will remain highly vulnerable to future seismic disasters.

CHAPTER-VIII

RECOMMENDATIONS

8. Future Outlook: Strategies for Mitigating Seismic Risks in Delhi

Given Delhi's high seismic vulnerability, implementing long-term risk mitigation strategies is essential to minimize casualties, structural damage, and economic losses during an earthquake. A comprehensive approach involving stricter policy enforcement, structural retrofitting, early warning systems, public awareness programs, and collaborative efforts between government and private entities is crucial to enhancing Delhi's earthquake resilience.

8.1 Need for Strict Enforcement of Building Codes

Ensuring compliance with earthquake-resistant construction standards is a fundamental step in reducing seismic risks. The National Building Code (NBC) 2016 provides detailed seismic safety guidelines for structures in high-risk zones, outlining essential engineering requirements such as reinforced foundations, ductile design, and lateral load resistance (Bureau of Indian Standards [BIS], 2016). Mandatory adherence to these guidelines for all new constructions can significantly improve structural safety (Jain, 2020). However, enforcement remains weak due to inadequate monitoring and lack of accountability. To address this, municipal authorities must conduct regular audits and impose strict penalties for non-compliance, ensuring that all construction projects integrate seismic-resistant features.

Unauthorized colonies present an even greater challenge, as most structures are built without engineering supervision or adherence to safety norms. Granting ownership rights without structural improvements does little to address the seismic risks (NDMA, 2019). Instead, policies should focus on retrofitting existing unsafe buildings and redeveloping high-risk settlements into planned, earthquake-resistant communities. Government intervention is necessary to regulate unauthorized construction, ensure safe redevelopment, and integrate informal housing areas into the city's disaster management framework.

8.2 Retrofitting and Strengthening Existing Structures

Retrofitting existing buildings is one of the most effective ways to enhance seismic resilience, but financial and logistical challenges often hinder large-scale implementation. To encourage homeowners and developers to invest in structural reinforcements, the government should introduce subsidies, tax benefits, and low-interest loans for retrofitting (Shukla & Joshi, 2017). Simplifying building regulations related to structural modifications can further incentivize safety upgrades by reducing bureaucratic hurdles.

Public-private partnerships (PPPs) can accelerate retrofitting efforts by leveraging financial and technical resources from private developers and international organizations. Collaborations between government agencies, construction firms, and engineering experts can lead to cost-effective safety improvements. Pilot retrofitting projects in high-risk zones can demonstrate affordable and efficient solutions, encouraging wider adoption across vulnerable areas. By integrating retrofitting incentives with urban renewal projects, Delhi can gradually transform its aging infrastructure into a more earthquake-resilient city.

8.3 Creating an Effective Early Warning and Response System

A well-developed seismic monitoring and early warning system can save lives by providing timely alerts before an earthquake strikes. Installing a network of seismic sensors across Delhi would enable real-time detection of tremors and improve predictive capabilities (Gupta, 2006). Integrating these sensors with artificial intelligence (AI)-based forecasting models can enhance accuracy and response times, allowing authorities to issue early warnings (Sinha & Goyal, 2019).

An effective earthquake alert system should include mobile notifications, sirens, and public address systems in high-density areas. Mobile-based alert systems can warn residents a few seconds before strong shaking begins, enabling them to take immediate protective actions (NDMA, 2019). Additionally, public sirens and automated announcements in crowded places such as markets, metro stations, and residential complexes can help facilitate quick evacuations. By investing in advanced seismic monitoring technology and ensuring widespread accessibility to early warnings, Delhi can significantly reduce earthquake-related casualties.

8.4 Public Awareness and Community Participation

Public education and community engagement play a critical role in disaster preparedness. Many casualties during earthquakes occur due to a lack of awareness about safety measures. Introducing earthquake safety programs in schools and workplaces can train individuals on survival techniques such as "Drop, Cover, and Hold" (Jain, 2020). Awareness campaigns targeting local communities can provide guidance on securing household items, identifying safe zones, and preparing emergency kits.

Large-scale emergency drills are equally important to ensure an organized response during an earthquake. The National Disaster Response Force (NDRF) and Delhi Disaster Management Authority (DDMA) should conduct periodic evacuation and response drills in high-risk zones. These drills should simulate real-life scenarios, including building collapses and rescue operations, to familiarize residents and emergency personnel with effective response strategies. Additionally, clearly marked evacuation routes and signage should be installed in residential and commercial areas to guide people to safety in case of a major earthquake.

8.5 Role of Government and Private Sector in Disaster Management

A coordinated effort between government agencies, urban planners, and the private sector is essential for effective earthquake risk management. The National Disaster Management Authority (NDMA), DDMA, and municipal corporations must work together to develop a comprehensive seismic risk reduction strategy (NDMA, 2019). Strengthening communication between these entities can enhance emergency preparedness, streamline response protocols, and ensure efficient resource allocation during a disaster. Establishing clear post-earthquake response procedures for emergency services such as fire brigades, medical teams, and rescue squads can significantly improve disaster response efficiency.

Private sector involvement is also crucial in promoting safer construction practices. Real estate developers should be incentivized to adopt seismic-resistant designs through financial benefits such as reduced taxes or subsidies. Strict penalties for developers who fail to comply with safety regulations can further ensure accountability. Additionally, promoting earthquake insurance can encourage property owners to invest in safer construction, as financial security would motivate them to prioritize structural resilience (Sinha & Goyal, 2019).

By integrating strict regulatory measures, financial incentives, advanced warning systems, and public engagement initiatives, Delhi can significantly reduce its earthquake risk. Proactive policy interventions, coupled with technological advancements and community participation, will play a crucial role in mitigating the devastating impact of future seismic events.

CHAPTER-IX

CONCLUSION

Delhi's growing seismic vulnerability stems from rapid urbanization, unregulated construction, and the presence of unauthorized colonies that lack structural resilience. Despite being located in a high-risk seismic zone, the city's preparedness remains inadequate, with many buildings failing to meet earthquake-resistant standards. The absence of strict regulatory enforcement, poor urban planning, and insufficient public awareness further amplify the risks.

To mitigate potential devastation, a multi-faceted approach is required—one that integrates strict enforcement of seismic building codes, large-scale retrofitting of unsafe structures, and the development of an advanced earthquake early warning system. Public awareness campaigns and emergency preparedness drills must be prioritized to equip citizens with the knowledge and skills needed to respond effectively during an earthquake. Additionally, collaborative efforts between government agencies, private developers, and international organizations can accelerate the adoption of safer construction practices and disaster management strategies.

Given Delhi's increasing exposure to seismic threats, proactive measures must be implemented urgently to prevent large-scale casualties and economic losses. Strengthening infrastructure resilience, enhancing policy enforcement, and fostering community engagement will be key to ensuring long-term safety. Without immediate and sustained action, Delhi remains highly vulnerable to a catastrophic earthquake that could have far-reaching consequences for its residents and economy.

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