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SDGs, Indian Cities and Seismic Sustainability

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ABSTRACT Goal 11 of the UN Sustainable Development Goals aims to "make cities and human settlements inclusive, safe, resilient and sustainable." Its targets include the promotion of resilience to disasters such as earthquakes. Many of India's cities that lie the high-intensity zones—determined by 'seismic microzonation'—are extremely vulnerable to earthquakes. Such cities, therefore, must move towards developing and adopting policies that promote seismic sustainability. These include sound urban planning, promoting municipal infrastructure, issuing regulations on development projects, and retrofitting old structures. Ideally, these policies should include a strategy for incentives to fund cost-effective construction for seismic resilience.

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INTRODUCTION

Seismic sustainability is among the various factors that make cities safe and resilient. Seismic sustainability refers to the capacity of built structures to withstand the impact of earthquakes by incorporating certain benchmarks during construction.[1] The most useful tools to determine seismic sustainability include vibration control, which augments the seismic fitness of structures, and base isolation, an assembly of special units that separate a building from the shaking ground, thereby enhancing its seismic performance.[2] While these are recently developed specialised components, buildings can also be made earthquake-resistant by merely complying with stipulated standards.

Scientists are yet to discover the tools to predict seismic occurrences with accuracy, but know what causes them.[3] "An earthquake is caused by a sudden slip on a fault. The tectonic plates are always slowly moving, but they get stuck at their edges due to friction. When the stress on the edge overcomes the friction, there is an earthquake that releases energy in waves that travel through the earth's crust and cause the shaking that we feel".[4] The primary cause for frequent and high-intensity earthquakes in the country is the Indian plate driving "into Asia.... and causing a steady, but unpredictable, sequence of earthquakes in Asia and parts of India."[5] This brief looks at the seismic sustainability of Indian cities in light of the targets determined in the UN Sustainable Development Goals (SDGs),[6] and how this can be achieved by making it a part of urban and municipal planning.

SDG 11 AND SEISMIC SUSTAINABILITY

The UN adopted the 17 SDGs in September 2015 following the culmination of its Millennium Development Goals (MDGs). While the MDGs primarily targeted countries with a developmental backlog, the SDGs are universal developmental goals that apply to all countries,[7] to be achieved by the end of 2030. SDG 11 focuses on cities, aiming to "make cities and human settlements inclusive, safe, resilient and sustainable."[8]

According to SDG target 11.5, by 2030, cities should "significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters."[9] Furthermore, by 2020, SDG target 11B prescribes a substantial increase in the number of cities and human settlements that adopt and implement integrated policies and plans towards, among other things, "mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels."[10]

The Sendai Framework, endorsed by the UN General Assembly, is a "roadmap for how we make our communities safer and more resilient to disasters."[11] It aims to achieve "the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries over the next 15 years."[12] The targets urge the international community to "support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilising local materials."[13]

While the words 'seismic sustainability' are not explicitly used in the text of SDG 11 and its targets, their reading indicates that seismic resilience is a key step to achieve the goals that aim to reduce human and material losses due to natural disasters. Earthquakes are among the most destructive of all natural disasters. India and its cities should pay particular attention to measures that can help achieve seismic sustainability.

INDIA AND SEISMIC VULNERABILITY

India has faced many destructive earthquakes. According to the National Disaster Management Authority, more than 58.6 percent of India's landmass is prone to earthquakes of moderate to very high intensity.[14] In the last nine decades, India has seen at least five highly powerful earthquakes, in addition to the numerous others that were less destructive.[15] In 1934, for instance, Bihar was ravaged by an earthquake of unprecedented intensity (8.1 magnitude), which is still one of the worst earthquakes in Indian history. Over 30,000 people were killed in the disaster, thousands were injured, and there was extensive loss of property. Although the epicentre was in eastern Nepal, the earthquake was so strong that tremors were felt even 650 km away in Kolkata.[16] "Most buildings tilted and slumped bodily into the ground in an area of about 300 km long and of irregular width, sometimes exceeding 65 km."[17]

The 1950 Assam earthquake, meanwhile, had a magnitude of 8.6 on the Richter scale, with the epicentre at Rima in Tibet. The earthquake caused widespread destruction in both Assam and Tibet, with over 1,500 people killed in Assam alone.[18] In 1991, a 6.1 magnitude earthquake hit the districts of Uttarkashi, Chamoli and Tehri in present-day Uttarakhand, killing about a thousand people, injuring over 5,000 and causing extensive damage to property. Even distant regions like Delhi experienced tremors due to the quake. [19] More than 10,000 people were killed in the 1993 Maharashtra earthquake (6.4 magnitude). Over 52 villages around the epicentre (Latur) were wholly decimated, with some villages seeing a death toll as high as 30 percent of their population.[20] In 2001, Gujarat was hit by a 7.7 magnitude earthquake, in which over 20,000 people were killed. Several towns and villages were destroyed in the catastrophe, with Bhuj among the worst affected.[21]

India has recently seen many earthquakes of less intensity. On 5 June this year, an earthquake of magnitude 4.0 on the Richter Scale shook Hampi in Karnataka. The same morning, Jamshedpur in Jharkhand was also jolted by an earthquake of magnitude 4.7.[22] Delhi and the National Capital Region (NCR) have also been subjected to repeated tremors. Over the last two years, the region experienced 64 earthquakes with magnitudes ranging between 4.0 and 4.9, eight with magnitudes 5.0 and above. Eleven tremors were felt in the NCR region in the last two months, with the most recent being near Noida on 3 June. Geophysics and seismology experts at IIT Dhanbad have predicted that given the increase in the accumulation of strain energy in the region, Delhi and the NCR may soon be hit by a major earthquake.[23]

Costs of Earthquakes

Of all the natural disasters, earthquakes can be the most devastating, with the level of destruction dependent on the magnitude and the infrastructure and human density where they occur. Losses can be in the form of human deaths and injuries, damage to property and infrastructure, and significant disruption in economic activity which has prolonged impacts.

For instance, damages from the Latur earthquake were approximately US$333 million,[24] and losses from the Gujarat earthquake were estimated at US$ 1.3 billion.[25] Similarly, the earthquake that hit Japan's Honshu island in 2011 (9.0 magnitude) caused losses estimated at USD$231,806 million. The damages from the 2010 earthquake in New Zealand's Christchurch (7.0 magnitude) were calculated to be US$7,064 million. The 1994 earthquake in California's Northridge (6.7 magnitude) caused losses worth US$63,957 million.[26]

Seismic Zoning Map of India

Earthquake magnitude and earthquake intensity can help explain the severity of the hazard. "Earthquake magnitude is a measure of the size of the earthquake, reflecting the elastic energy released by the earthquake. This is referred to by a certain real number on the Richter scale (e.g., magnitude 6.5 earthquake). On the other hand, earthquake intensity indicates the extent of shaking experienced at a given location due to a particular earthquake. This is referred to by a Roman numeral (e.g., VIII on MSK scale)."[27]

A scientific way of looking at the earthquake vulnerability of different areas is by carrying out 'seismic microzonation'. Seismic microzonation is the process of subdividing a region into smaller areas that have varied potential for or susceptibility to hazardous earthquake effects.[28] The National Centre for Seismology (NCS), working under the India Meteorological Department, records earthquakes and carries out studies on the microzonation of India's cities.[29] An early seismic zoning map divided India into five seismic zones. This has since been revised by the Bureau of India Standards (BIS) and is available as part of the earthquake-resistant design code [IS 1893 (Part 1): 2016]. It assigns four levels of seismicity for India in terms of zone factors, from Zone V to Zone II (See Table 1).[30] The BIS's revisions of India's seismic zoning map has been done by considering earthquake records, tectonic activities and the damage caused.

According to this zoning map, Zone V has the highest level of seismic activity and falls in the 'very high damage risk' zone. Zone IV is the 'high damage risk' zone, Zone III the 'moderate damage risk' zone, and Zone II

Table 1: Seismic Zones in India and Intensity

Seismic Zone	Intensity	Intensity on Modified Mercalli scale*
Zone V	Very severe intensity zone	IX and above
Zone IV	Severe intensity zone	VIII
Zone III	Moderate intensity zone	VII
Zone II	Low intensity zone	VI or less

**measures the impact of earthquakes on the surface of the earth*

Source: Lok Sabha and IndiaSpend

the 'low damage risk' zone. No part of India falls under Zone I.[31]

The most vulnerable regions under Zone V are in the Himalayan and sub-Himalayan belt, and the Andaman and Nicobar Islands. The Himalayan ranges are among the world's youngest fold mountains, and so the subterranean Himalayas are geologically very active. Kashmir, Northeast India, Himachal Pradesh, Uttarakhand, Rann of Kutch in Gujarat, some parts of Jammu & Kashmir, and parts of North Bihar also fall in Zone V. The remaining parts of Jammu and Kashmir and Bihar, Delhi, Sikkim, Rajasthan, northern parts of Uttar Pradesh, parts of West Bengal and Gujarat, and small portions of Maharashtra near the west coast form Zone IV.

Zone III covers Kerala; Goa; the Lakshadweep islands; the remaining parts of Uttar Pradesh, Gujarat and West Bengal; and parts of Punjab, Rajasthan, Madhya Pradesh, Bihar, Jharkhand, Chhattisgarh, Maharashtra, Odisha, Telangana, Andhra Pradesh, Tamil Nadu and Karnataka. The remaining parts of the country fall in Zone II, which is the low-intensity zone and is identified as the Low-Risk Damage Zone.

Vulnerable Cities

India's cities are highly densely populated. It is thus likely that if an earthquake were to hit any city in the country, the destruction would be massive, and the process of rebuilding complex, lengthy and costly. It is in the interest of India's cities—and the people who live in them, especially those in the higher intensity zones—to plan for seismic resilience.

As of March 2016, 107 towns and cities across the country are seismically vulnerable.[32] Eight cities—Jorhat (population 1,090,000), Sadiya (population 102,000) and Tezpur (population 103,000) in Assam; Bhuj (population 214,000) in Gujarat; Darbhanga (population 267,000) in Bihar; Imphal (population 268,000) in Manipur; and Mandi (population 26,000) in Himachal—were added to the Zone V classification, which already included Guwahati (population 957,000) and Srinagar (population 1,180,000). The NCS has assessed that 29 cites that fall under the 'severe' (Zone IV) to 'very severe' (Zone V) seismic classification. These include Delhi (population 19,000,000), Patna (population 2,500,000) in Bihar, Kohima (population 115,000) in Nagaland, Gangtok (population 100,000) in Sikkim, Shimla (population 170,000) in Himachal Pradesh, Dehradun (population 578,000) in Uttarakhand, and the union territories of Puducherry (population 242,000) and Chandigarh (population 1,060,000). As per Census 2011, these cities had a combined population of around 30 million.[33] The next census, due in 2021, will show substantial population growth after a decade of greater urbanisation.

Many of India's megacities have been spared a major earthquake, which has led to a certain level of complacency.[34] Yet, many of these megacities and a substantial number of large metropolitan cities fall in the potentially troublesome zones (See Table 2). Earthquakes in cities that have high demographic and built density would lead to horrendous losses of life, property and economy.

Table 2: Megacities, Large Metropolitan Cities and Seismic Zones

SN	CITY	STATE	ZONE
1	DELHI	DELHI	IV
2	MUMBAI	MAHARASJTRA	III
3	KOLKATA	W BENGAL	III
4	CHENNAI	TAMILNADU	III
5	BENGALURU	KARNATAKA	II
6	HYDERABAD	TELANGANA	II
7	AHMEDABAD	GUJARAT	III
8	PUNE	MAHARASHTRA	III
9	SURAT	GUJARAT	III
10	JAIPUR	RAJASTHAN	II
11	KANPUR	UTTAR PRADESH	III
12	LUCKNOW	UTTAR PRADESH	III
13	NAGPUR	MAHARASHTRA	II
14	GHAZIABAD	UTTAR PRADESH	IV
15	INDORE	MADHYA PRADESH	III
16	COIMBATORE	TAMIL NADU	III
17	KOCHI	KERALA	III
18	PATNA	BIHAR	IV
19	VISHKHAPATNAM	ANDHRA PRADESH	II
20	KOZHIKODE	KERALA	III

Source: Press Information Bureau 2017

With a view to better monitor earthquakes in India, 31 additional earthquake observatories are being established,[35] taking the total number of observatories to 115. This will help detect and record earthquake parameters more accurately and identify possible precursors of tremors. The NCS has also surveyed cities like Delhi and Kolkata to study the likely impact of an earthquake in the megacities.[36]

Such governmental efforts must continue. But the circle of safety will remain incomplete unless cities themselves take steps to achieve seismic sustainability. The BIS's earthquake-resistant design standards, last updated in 2016, provide detailed stipulations for, among other things, residential and commercial structures as well as metros, flyovers and dams. However, many cities have ignored these standards during construction.[37]

MAKING CITIES SEISMICALLY SUSTAINABLE

Depending on the seismic zone they fall in, cities must proactively encourage safety and prevention, and prepare for any eventuality of seismic activity. First, cities must develop criteria to identify seismically vulnerable buildings. Since a vast majority of such buildings would likely be privately owned, the assessment of structures should be done after notifying them and with their cooperation. The owners may volunteer to do the vulnerability assessment themselves, which should be welcomed. Next, a cost estimate must be conducted for the kind of seismic retrofitting required. Since these costs will have to be borne by the owners, the municipal body must assist them in all feasible ways to lighten the burden, especially for the less affluent.

Making new structures seismically sustainable is a far easier process than retrofitting old structures. For new construction, seismic risk assessment and sustainability must be enforced. Cities will have to include the necessary steps and construction methodology in their development control regulations, moving from advisory suggestions to mandatory prescriptions for all new structures that come up in their jurisdiction. Cities must devise a package of incentives to encourage those constructing the structures to adhere to the seismic stipulations.

To make buildings more earthquake-resilient and create safe and sustainable structures for future generations, scientists have taken measures to analyse various vibrational modes. The key areas that still need attention are the reuse of recyclable materials, which cause less waste and pollution, the reduction of materials, and the construction of buildings to acquire resilience. The foundation must be designed in such a way that, when a seismic incident occurs, the superstructure is affected before the substructure, thus avoiding any foundational damage.

Seismic design could be subject to a lot of variety depending on the application of the factor of safety. For instance, a very high factor of safety to cover for the most extreme conditions may yield a highly sustainable structure. This, however, would escalate costs enormously. It is, therefore, important to find a wise balance between safety and cost to construct buildings with the right degree of seismic design.

A city's infrastructure has great significance in its resilience. The disruption caused by earthquake damage to infrastructure can have a significant cascading failure effect on municipal services, economic activity, and normal life. Improving the seismic sustainability of infrastructure will help avoid or lessen earthquake damage. However, just as with buildings, a balance must be achieved between seismic design and costs.

Encouraging retrofitting

Owners are likely to be reluctant to invest in making their buildings seismically safe. Seismic retrofitting, in most cases, will likely mean substantial work for several months and could turn into a significant investment.[38] The benefit of such investment is the imagined threat of an earthquake that may not even materialise during the lifetime of that structure. Retrofit interventions are also likely to be invasive; they may disrupt the lives of occupants and require residents to move out. In case the building is listed as a heritage structure, conservation concerns would complicate the matter. Additionally, access to capital may be difficult. And to top it, bureaucratic hurdles may plague the process of obtaining building permissions.

Owners would likely need a lot of persuasion and encouragement before agreeing to retrofit their buildings. "A positive example comes from Italy where the government has been offering tax credits, allowing subtracting 36–65% of refurbishment costs from the tax due, with deductions equally distributed over 5 or 10 years."[39] A further incentive is low-interest loans, which "have been lately getting more attention and are available in a number of countries".[40] Some countries have imposed a seismic label on buildings to rate their seismic safety. Others have promoted mandatory insurances to cover damage from natural hazards, including earthquakes.[41] Regulatory-based tools and measures are also used to encourage retrofitting works.

For the government, the simplest way to promote an incentive would be to make the measure obligatory. However, this method is usually unpopular and ineffective. A good step would be a mandatory, government subsidised insurance fund. But the best regulatory measure would be the one that combines some type of a financial incentive (for instance, obligatory seismic safety rating) with tax deductions following the seismic safety and energy efficiency rating.

Disaster risk reduction and urban planning

Since cities are facing rising disaster risks, the linkages between hazard mitigation efforts and urban planning in the context of building sustainable communities must be recognised. Sustainable communities demand sustainable urban design, which would include user-friendly public spaces, manageable densities and mixed-use development. Above all, there should be a recognition that disaster vulnerability imposes constraints on development. Spatial planning that does not take these factors into account put cities in a compromised position in the event of major disasters, such as earthquakes. Unfortunately, the rate of unplanned urban expansion and the partly unregulated building construction currently happening in most cities is exacerbating the losses that cities will sustain if a seismic event were to occur. Future urban planning, therefore, cannot exclude from its design considerations on the possibility of seismic and other disasters.[42]

Affordable housing and seismic resilience

The cost of seismic-centric construction will be a significant concern for affordable housing, where cost is key to making it available to the poor. All care must therefore be taken that in the search for seismic resilience, the cost factor is not ignored. This does not mean that such buildings should be constructed using cheap materials of substandard quality. Instead, they must be designed and constructed as any other building with regard to the foundation, structure and strength. The reduction in cost is primarily achieved through effective utilisation. It is possible to reduce construction cost through better management, appropriate use of local materials, skills and technology without sacrificing the performance and structure life[43]. Additionally, "the streamlined building process is designed in such a way that we can avoid expensive stoppages which are common on traditional building sites, where the builders have to wait for the electrician, then for the plumber, and new holes need to be drilled every time, wasting building material and time."[44]

About 35 percent of the cost can be saved through this model in comparison to conventional building techniques. Although the actual savings will only be determined by local labour costs, soil conditions and the overall size of the project, it is clear that the streamline building process and technology are competitive on a large scale for low-cost housing projects in comparison to similar units built with traditional techniques.[45]

Many sound local building practices are already operational in earthquake-prone areas. There are excellent examples of traditional constructions in India that are highly earthquake resistance, for instance, the Assam-type in Northeast India and *dhajji dewari* architecture used in construction in North India. In the hilly countryside of Nepal, houses with mud-bonded bricks or stones with a significant fraction of timber elements are built. They are symmetrical and may go up to two stories. The wooden components such as rafters and struts are introduced at openings. Roofing is generally done with seasoned stones properly tied with iron wires, providing an integral framework. The units are tied to purlins using wooden pegs. This method allows for load reduction in the upper floors. The openings are smaller, which increase its load-bearing support in addition to the wooden sill and lintel bands. The foundation had to be levelled despite the site being contoured. These features were later incorporated in the modern building codes.[46]

Professional capacity building

Even if cities include seismic sustainability in their development plans, the question of a sufficient pool of competent professionals—architects, engineers, masons—remains. There is a significant deficit in skills, which can be bridged through capacity building initiatives. Any capacity building programme must encourage a general awareness of seismic threats as well as the entire chain of people involved in the construction process—the building owner, the architect, the engineer, the contractor, the mason and the municipal official.[47] Furthermore, it needs to include primary knowledge of earthquake-resistant design. "It would also build capacity to develop plans to embark on large scale earthquake disaster mitigation in the country. The successes of these low-key but important initiatives will help prepare the country for the daunting task of developing earthquake resistance in its built environment at the earliest opportunity."[48]

Some important work in this area has already begun.The home ministry's National Disaster Management Division runs a National Programme for Capacity Building of Architects in Earthquake Risk Management. The objectives of the programme are to "ensure seismically safer habitats by training of practicing architects, capacity building of the Colleges of Architecture at the National and State levels for ensuring effective training of practicing architects in earthquake safety, development of resource materials/ training modules for sensitisation/training architects and putting in place a system of training and subsequently of certification for practicing architects."[49] This effort is supplemented by state governments and institutions that focus on structural engineers. Furthermore, the National Information Centre for Earthquake Engineering based at IIT Kanpur maintains an extensive repository of updated knowledge on earthquakes, disseminating it across the country. It has also conducted workshops under the National Programme on Earthquake Engineering Education for structural engineers and architects.[50]

Masons are an equally significant component in the battle against earthquakes. It is, therefore, vital to teach them the basic technique of constructing earthquake-resistant buildings along with various engineering methodologies for building in the seismically active zones. States that are under threat of earthquakes would do well to concentrate on mason training.

Despite these efforts, given that large parts of India are seismically vulnerable, much more needs to be done to enhance the capacity of professionals. Since science and technology on earthquakes are dynamic, such capacity enhancement needs to be an ongoing exercise.

CONCLUSION

Seismic sustainability stands on the pillars of environment, society and economy, and has a vital role in disaster risk reduction and achieving sustainability. The Indian government provides an overall analysis of urban vulnerability and keeps updating seismic microzonation, which is made available to the local governments and the public as well. The states, as the constitutionally mandated authorities for urban development, must assist city governments in the preparation of statutory prescriptions to promote seismic resilience, and in devising appropriate incentive mechanisms for seismic retrofitting and construction of buildings and urban infrastructure.

City governments must engage with their citizens and urge them to heed to seismic sustainability requirements. The states and urban local bodies will have a special role to play in making affordable housing seismically resilient. All these authorities must together consider the question of how urban planning can aid disaster reduction. This decision will need to strike a balance between city economy, environment and demographic density. These composite measures will go a long way in fulfilling India's commitment to achieving Goal 11 of the UN SDGs. ORF

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