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Innovative Materials for Earthquakes Resistant Buildings.

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Abstract:

Earthquakes indicate changes within the Earth's internal structure and occur globally, with their frequency varying based on local tectonic conditions. Historically, earthquakes have caused significant loss of life and damage to infrastructure, disrupting a country's social and economic stability. While prevention of earthquakes is impossible, damage can be mitigated through the construction of earthquake-resistant buildings. With increased understanding of earthquakes, many countries now incorporate seismic provisions in their building codes and architectural designs.

During an earthquake, seismic waves originate from the focus and spread in all directions as body waves and surface waves, which are highly unpredictable. These ground motions make buildings vibrate and generate inertia forces within their structural components. Without proper seismic design, buildings may collapse, leading to catastrophic outcomes. The primary aim of seismic design is to ensure the safety of occupants and maintain the functionality of buildings.

Keywords: Earthquakes , Materials, Techniques, Buildings.

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Introduction:

Earthquakes can cause extensive damage to infrastructure and loss of life. From 1990 to 2010, India experienced over nine major earthquakes, resulting in about 30,000 deaths. While certain regions, such as those in seismic zone V according to IS 1893 (Part 1) - 2016, are more prone to earthquakes, no area in India is completely safe from this threat. Numerous minor earthquakes occur daily. The poor performance of buildings during past earthquakes has revealed their vulnerability, leading engineers and architects to prioritize designing more seismically efficient structures. Approximately 60% of India's landmass is at risk of moderate to very severe earthquakes. A major earthquake in a sparsely populated area may cause less damage than a moderate one in a densely populated area. Field surveys after significant earthquakes show that most casualties are due to building collapses. The lack of seismic knowledge and its application in building design and construction results in structural failures. Many rural and urban buildings are low-rise, non-engineered structures that are most susceptible to damage. During an earthquake, seismic waves radiate in all directions, with horizontal vibrations being particularly significant in causing structural failures. These waves cause the building's foundation to move, generating inertial forces in the structural elements. The seismic performance of a building during an earthquake is influenced by its shape, size, and geometry. and load path characteristics. The seismic design The philosophy of seismic design aims to protect both structures and human life. It requires that load-bearing elements stay undamaged during minor, frequent shaking, sustain repairable damage during moderate, occasional shaking, and endure severe damage without collapsing during rare, strong shaking. This study examines the construction practices used for these common building types. Recommendations are provided for local construction practices where necessary, with reference to code provisions. Additionally, the study discusses potential future trends in earthquake-resistant technology.

Objectives of the Research:

This research seeks to investigate the effects of earthquakes on both conventional and earthquake-resistant buildings. Additionally, it aims to examine advanced materials that enhance earthquake resistance in building structures, along with methodologies for their development.

More specific goals include:

- Investigating and identifying novel materials that could enhance earthquake resilience in buildings.

- Evaluating the mechanical and structural characteristics of innovative materials under seismic conditions.
- Contrasting the performance of these innovative materials with conventional construction materials during earthquakes.
- Conduct a cost-effectiveness assessment of employing advanced materials in earthquake-resistant construction.
- Assess the environmental footprint and sustainability of advanced materials.
- Devise methodologies and strategies for integrating advanced materials into current construction practices.
- Conduct field trials and simulations to verify the efficacy of advanced materials in real earthquake conditions.
- Ensure compliance of advanced materials with established building codes and seismic resistance standards.
- Offer guidance to policymakers, engineers, and architects regarding the utilization of advanced materials in earthquake-resistant building designs.

I. Necessity for Earthquake-Resistant Construction:

There are more than 330 million housing units in the country, predominantly rural, as two-thirds fall into this category. India's Geological Survey has categorized the nation into four seismic zones, with zones IV and V containing around 30% of these homes. These rural structures often use local materials like mud, unburnt bricks, stone, or burnt bricks, making them susceptible to earthquakes if poorly constructed or maintained.

In addition to the large rural housing sector, India has experienced rapid urban growth. The urban population increased by 32% from 2001 to 2011, reaching 377 million, and is projected to approach 590 million by 2030. The construction demand stems significantly from infrastructure projects (50%) and other sectors such as industry, residential, and commercial developments.

The timing of earthquakes significantly affects casualties due to building occupancy. For example, the 1993 Latur earthquake struck at 3:53 AM when most were asleep, while the 2001 Bhuj earthquake hit at 8:46 AM with more people awake, resulting in lower casualties. Both events highlighted vulnerabilities in non-engineered structures like random rubble masonry in mud mortar and modern multi-story RC framed buildings.

These incidents underscore the need for seismic design in modern residential buildings and emphasize integrating seismic principles into structural planning to ensure buildings function cohesively during earthquakes. Rural communities must

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be educated about earthquakes and the importance of earthquake-resistant construction. In urban areas, careful initial planning and design are crucial to support buildings that perform well under seismic stress.

II. Earthquake-Resistant Construction Practices for Buildings:

Masonry has long been a common building material throughout history. Prominent examples of ancient masonry include the Taj Mahal in Agra, the Pyramids in Cairo, and the Colosseum in Rome. Typically, masonry structures are brittle and highly susceptible to seismic activity. Past earthquakes have shown that masonry buildings in rural areas often suffer severe damage or complete collapse. Therefore, designing these buildings to be earthquake-resistant is crucial.

Over the years, researchers have diligently sought ways to enhance the seismic resilience of masonry structures. Their efforts have resulted in the development of new earthquake-resistant technologies and construction methods. In India, various types of masonry units are used, such as clay bricks (both burnt and unburnt), concrete blocks (both solid and hollow), and stone blocks. Masonry buildings consist mainly of three key components: the roof, walls, and foundation, with the walls being the most vulnerable to damage from horizontal forces during earthquakes.

To ensure good seismic performance, the following conditions must be applied:

a. Walls are vulnerable elements and can fail when subjected to forces in their weaker direction. To mitigate this, create a strong bond between adjoining walls so that those loaded in their weaker direction can leverage the lateral resistance of walls loaded in their stronger direction. Additionally, reduce the risk of walls toppling by controlling their length-to-thickness and height-to-thickness ratios.

b. Windows and doors create weak points in masonry walls, so their sizes should be kept small. Reinforce these openings with steel bars to prevent cracks from forming and spreading.

c. Enhance the stability of junctions by ensuring good interlocking of masonry courses.

d. Use low-porosity bricks that have been pre-soaked to reduce water absorption from the mortar.

e. The strength of the mortar binding the bricks is essential. A cement-sand mortar with lime is recommended, as it offers excellent workability, flexibility during minor earthquakes, and strong bonding with bricks.

Methodology:

III. Modern Construction Techniques and Materials for Earthquakes Resistant Buildings:

1.Shape Memory-alloys:

Shape-memory alloys have exceptional properties that make them perfect for earthquake-resistant structures. They can absorb a large amount of energy without suffering significant damage or permanent changes in shape. The most prevalent types of shape-memory alloys are metal combinations like copper-zinc-aluminum-nickel, copper-aluminum-nickel, or nickel-titanium. This innovative material is the focus of extensive research to explore its diverse applications.

Figure 1: Details of shape-memory alloy–rubber bearing by Das and Mishra (2014)

2.Base Isolation :

Base isolation is a well-known and commonly used method to protect buildings from seismic forces. This technique involves a series of structural components that separate the building's superstructure from its substructure. During an earthquake, the ground beneath the building's foundation moves laterally, but the base isolation system permits this movement while preserving the building's structural integrity. Earthquake engineers, especially in Japan, the USA, and New Zealand, are increasingly focused on base-isolated systems, striving to develop more cost-effective solutions with applicability.

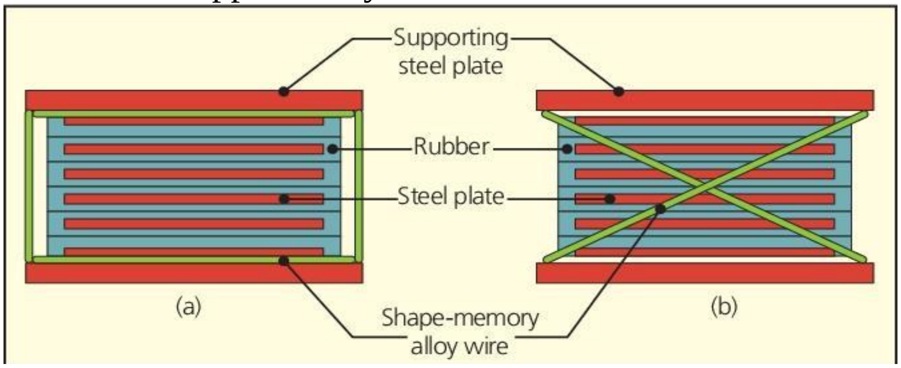

Figure 2: , Scientific Research Gate. https://www.researchgate.net/figure/LRB-system_fig1_286508808

3. Seismic Dampers Diagonal braces in moment-resisting frames have traditionally served as an effective system for resisting lateral loads. However,

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recent developments in controlling structural seismic response have led to the replacement of these braces with seismic dampers. These dampers operate similarly to hydraulic shock absorbers in cars, where most sudden shocks are absorbed by hydraulic fluids, thus transmitting minimal force to the car's chassis. When seismic energy passes through the dampers, they absorb a portion of it, reducing the force acting on the structure. Common types of seismic dampers include viscous dampers, which absorb energy through silicone-based fluid.

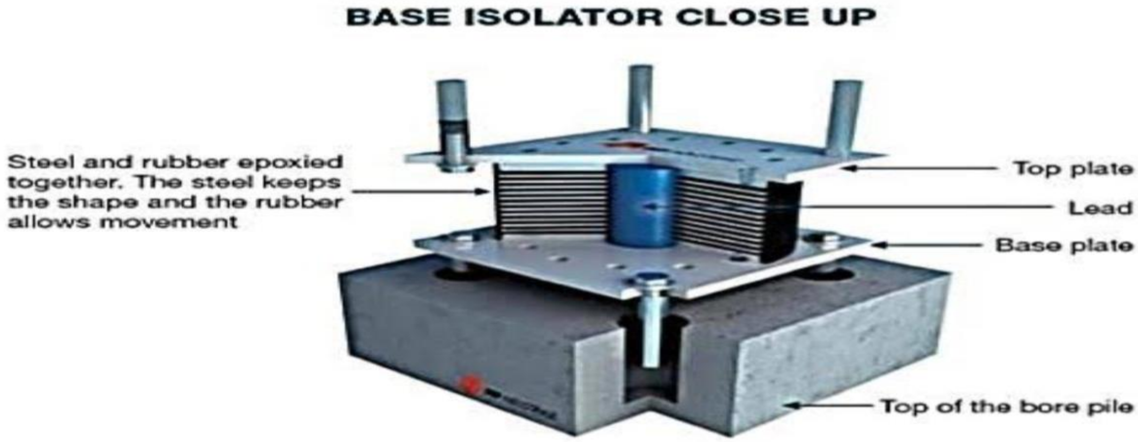

Figure 3: Seismic Energy Dissipation Devices (Abarkane et al, 2017)

Friction dampers, which absorb energy through friction between rubbing surfaces, and yielding dampers, which do so through the deformation of metallic components, are common types of seismic dampers. In India, friction dampers have been installed in an 18-story reinforced concrete frame building in Gurgaon.

4. Steel Plate Shearwalls:

Shear walls are essential elements in systems designed to resist lateral loads, and steel is highly regarded for its ductility. By merging these advantageous properties, a highly efficient load-resisting system has been developed, now commonly employed in Japan and North America. These shear walls are designed to bend rather than buckle under lateral forces. They are significantly thinner and lighter, which helps to reduce the overall weight of the building. Moreover, these walls do not need curing, which speeds up the construction process.

5.Carbon Fibers:

Researchers in Japan have studied the tensile properties and durability of carbon fibers, likening them to a spider web. In Nomi City, Ishikawa Prefecture, engineers have constructed an earthquake-resistant building using carbon fabric, designed to emulate the strength of a giant spider web. This building represents the world's first use of carbon fiber material for seismic reinforcement.

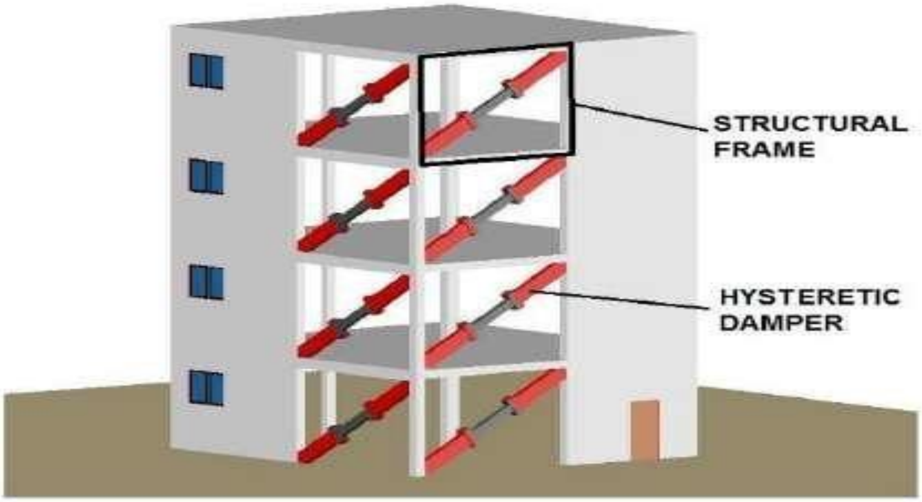

Figure 4: The use of carbonfibers for constructing an office building resembling a spider web(http://www.ecobuildingpulse.com)

IV. Future Trends :

1.Blue mussels. Mussels can be found attached to rocks and sea decks along the entire New England coast. They anchor themselves using fibrous strands that extend from between their shells. These strands, called byssal threads, are adhesive and enable mussels to remain securely in place, even during strong high tides. Researchers are investigating how to integrate the flexibility and elasticity of these threads into building structures to improve their resilience.

Figure 5: A Blue mussel found along the coast of New England. (https://www.nbcnews.com/science)

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2.The Rocking Frame A team led by Deierlein at the Blume Earthquake Engineering Center in the USA is developing an innovative technology known as the rocking frame. This system comprises three main components: steel frames, steel cables, and steel fuses. During seismic events, the fuses absorb energy while post-tensioning cables return the frame to its original position. When an earthquake occurs, the steel frames sway vertically. The energy is directed downwards to a component containing tooth-like fuses. These fuses may grind together or fail, but the frame itself remains intact. Once the shaking subsides, the steel cables within the frame pull the building upright again. Workers then inspect and replace any damaged fuses. This design allows buildings to be quickly reoccupied after an earthquake, providing a significant advantage.

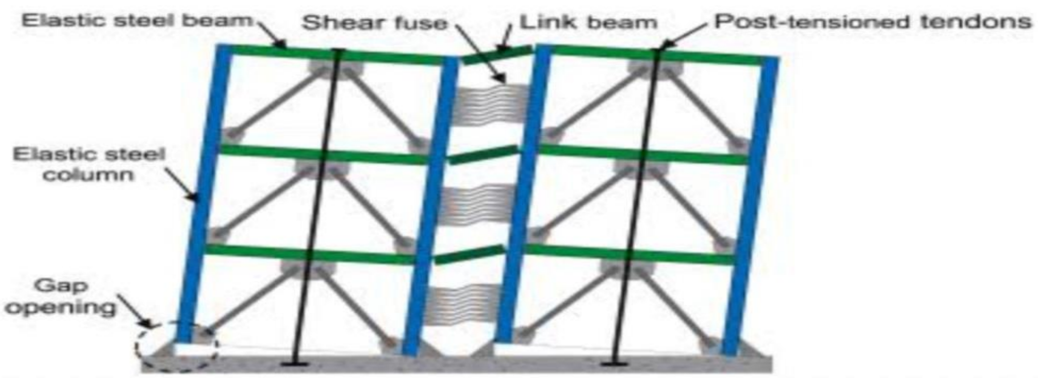

Figure6
https://www.sciencedirect.com/science/article/pii/S235271022400175X#f3

3. **Levitating Houses**.

A Japanese company has developed a concept where a house is normally supported by a deflated airbag. When sensors detect vibrations, they trigger a compressor that inflates the airbag. This raises the house by 3cm off its foundation. The house stays elevated throughout the earthquake, and once it ends, the airbag deflates, returning the house to its original position. This technology is suitable for new homes of appropriate weight and can also be applied to retrofit existing houses.

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Figure 7: Levitating house by deploying airbags.(http://award.designtoimprovelife.dk/nomination/243)

Results of Study:

Ideally, categorization based on construction type should consider the structural system, load transfer mechanism, predominant materials used, and performance during previous earthquakes. Buildings are typically classified by material type into categories such as:

- Masonry and Mortar
- Structural Concrete
- Steel
- Wooden Structures

Buildings categorized by construction materials are further classified based on their vertical and/or lateral load-resisting systems. For instance, structural concrete buildings may employ moment-resisting frames or shear walls depending on their specific load-resisting system.

Buildings constructed with bamboo primarily feature thatched roofs.

Several factors influence a building's seismic performance, including its natural frequency response to ground vibrations. This response is dictated by the building's inherent mass and stiffness, which can vary with height and affect its susceptibility to seismic events. Therefore, in regions with higher seismic risks, building height limitations are often determined based on local seismic hazard assessments.

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Structural irregularities, both horizontal and vertical, can disrupt the load path within a building, affecting the transfer of forces from the roof to the foundation. Detailed guidelines regarding these irregularities are outlined in IS 1893.

Local construction practices, adherence to building codes, and the level of maintenance or aesthetic considerations significantly influence construction quality, thereby impacting seismic performance.

In regions characterized by sloping terrain, such as the Himalayas, the Eastern and Western Ghats, and the North-Eastern states, many buildings are situated on hill slopes. These slopes are categorized as gentle (≤ 20°) or steep (> 20°). On gentle slopes, the ground is typically leveled before construction begins. However, on steep slopes, foundations may vary in elevation, resulting in vertical members with differing mass and stiffness, which can lead to vertical irregularities in buildings.

Recommendations:

- Enforce height restrictions for buildings in high seismic zones based on regional seismic hazard assessments to minimize vulnerability and ensure that structures can better withstand seismic forces.
- Avoid horizontal and vertical irregularities in building design to ensure a continuous and unobstructed load path from the roof to the foundation
- Follow guidelines and standards such as IS 1893 to mitigate the impact of any unavoidable irregularities.
- Ensure strict adherence to building codes and standards during construction to guarantee high-quality workmanship.
- Implement regular maintenance schedules and visual inspections to maintain the integrity and appearance of the structure over time.
- For buildings on gentle slopes (≤ 20°), level the ground before construction to provide a stable foundation.
- For buildings on steep slopes (> 20°), design foundations that account for variations in elevation to maintain uniform mass and stiffness in vertical members.
- Conduct training programs for architects, engineers, and construction workers on seismic-resistant design and construction practices.

Conclusion:

In conclusion, the exploration of innovative materials for earthquake-resistant buildings has demonstrated promising advancements in enhancing structural resilience. Materials such as carbon fiber, advanced composites, and damping systems like friction and yielding dampers show great potential in improving a

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building's ability to withstand seismic forces. These materials offer benefits such as increased strength, flexibility, and energy dissipation capabilities, which are crucial for mitigating damage during earthquakes.

Furthermore, the integration of these innovative materials into building design and construction holds the promise of creating safer and more sustainable structures in seismic-prone regions. Continued research and development in this field are essential to further refine these technologies, optimize their performance, and ensure their practical application in real-world settings.

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