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Earthquake-Proof Building Materials for Earthquake-Prone Areas

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ABSTRACT

The Quetta earthquake of 1935 caused significant loss of lives and property due to non-engineered construction within the city. Building construction and design in developing countries is often overlooked due to the high cost of implementing construction codes that consider seismic considerations. To tackle this problem, a skeleton system has been developed that aims to protect lives and properties during an earthquake in contrast considering the availability of materials and financial limitations of people. The skeleton system offers an affordable and effective solution for seismic-resistant building design and construction. The system has been adapted to meet the needs of different climates and can easily be customized to meet specific requirements.

1. INTRODUCTION

Communities face immense danger from natural disasters, which can damage buildings and harm people, often resulting in long-lasting impacts. Earthquakes, hurricanes, floods, and wildfires are just a few examples of catastrophic events that can lead to the destruction of critical infrastructure and the loss of countless lives. Overcrowding, weak building codes, and geographic vulnerabilities can exacerbate the severity of these disasters. This research paper aims to investigate the complex relationship between natural disasters, people, and buildings, and explore the mechanisms that cause harm. Through an analysis of case studies, statistics, and scholarly findings, we aim to gain a deeper understanding of the intricacies at play and propose potential strategies to mitigate the devastating effects of natural disasters. By drawing on past lessons, we can enhance our resilience and better prepare for future calamities (Ghosh & Kolathayar, 2021).

The design philosophy of structures has been modified to some degree with the advancement of structural and civil engineering. In severe circumstances, conventional building materials might not be able to achieve the goals of high-performance structural design. For instance, structural engineers can now design new buildings to predict ductile behavior during strong earthquakes to ensure safety and prevent collapse. This approach relies on "sacrificial" structural members that experience significant inelastic deformations at plastic hinge zones to provide energy dissipation (Ivanova & Filimonov, 2023). But as previous earthquakes have demonstrated, this kind of focused inelastic deformation can cause permanent or residual drifts and is linked to difficult-to-repair damage. As a result, these damaged buildings must eventually be demolished, which causes significant socioeconomic losses because of the expense of rehabilitation and the disruption of building services. The demands of contemporary resilient and sustainable civil/structural engineering cannot be met by the design concepts as they stand. Thus, the development of improved materials has been considerably aided by the search for high-performance structures (Ghafoori et al., 2022).

There are two basic types of buildings, engineered and non-engineered. Those buildings built through standard methods and with the help of professionals are called engineered buildings. The future consequences and the life period of the building are also kept in mind when engineers construct it. In contrast, non-engineered buildings are those that are built with non-standard and non-engineered methods (Sandaker et al., 2022). Building codes and regulations are not followed. Cement, steel, stones, and burnt bricks are some engineering materials that are used in buildings to overcome the effects of earthquakes. These materials are costly and can be used only by the people who can afford them. In contrast, mediocre people can afford materials such as wood, grass, and clay used for their economic construction (Tang et al., 2023). A skeleton system is proposed for an earthquake-proof building that can be used all over the world by reach as well as by common people.

1.1 DATA COLLECTION

From 2014 to 2023, Quetta has had a variety of seismic occurrences of differing magnitudes for ten years. The seismic data offers important insights into the city's susceptibility to tectonic disruptions by illuminating variations.

in the seismic activity in the area. Quetta has had earthquakes of varying magnitudes over this time, underscoring the importance of continued monitoring and preparedness measures. The statistics emphasize how crucial it is to develop disaster preparedness and management plans to reduce potential dangers related to seismic events. These results highlight the necessity for ongoing attention and community awareness in earthquake-prone areas by serving as a reminder of the region's dynamic and seismically active nature (Basharat et al., 2022).

Here is some of the data that I have collected about the earthquake in the last 10 years about Quetta. The International Institute of Earthquake Engineering and Seismicity (IIEES) and the United States Geological Survey (USGS) provided the data for this study. The time frame for the analysis was 2014 to 2023. Figure 1.1 displays the annual earthquake frequency in the region during the time under consideration. The year 2021 had the most earthquakes ever recorded.

The graph that shows Quetta's earthquake statistics from 2014 to 2023 gives an overview of the seismic activity that has occurred in the area throughout the last ten years. The graph, which shows patterns and changes in seismic occurrences by displaying earthquake magnitude over time, may be used to identify periods of increased or decreased activity. Understanding the region's susceptibility to tectonic disturbances and the city's seismic danger can both be gained from analyzing this data. It also emphasizes how crucial it is to take preventative action to prepare for earthquakes and increase resilience in seismically active areas. Researchers and local authorities can both benefit from using the graph to estimate earthquake risks and take appropriate action (Jamal-ud-din et al., 2023).

Table 1Earthquakes in Quetta in the last 10 Years

YEAR	MAGNITUDE
2023	4.1
2022	4.6
2021	5.9
2020	5.5
2019	5.0
2018	4.7
2017	5.0
2016	5.5
2015	4.2
2014	4.9

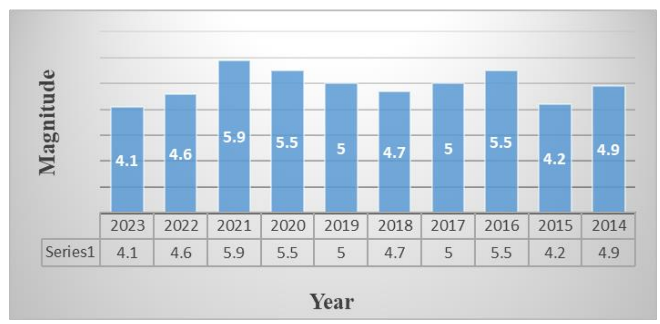

Figure 1 Magnitude of Earthquake in Each Year

1.2 CAUSES OF EARTHQUAKE

Defects in design, construction, or material quality are frequently the cause of buildings' inability to withstand earthquakes. Buildings might not be able to withstand earthquakes for the following frequent reasons.

1.2.1 INERTIAL FORCES

Buildings collapse due to inertial forces. During the earthquake, the lower portions of the earth which are in direct contact with the ground vibrate more. In contrast, the upper portion of the building remains at rest due to inertia. The resultant stresses increase the frequency of vibrations and thus collapse the building (Sambare et al., 2012).

1.2.2 POOR CONSTRUCTION MATERIALS

Structures with low-quality building materials are more affected by the earthquake and in the past, this is experienced un-engineered buildings were mostly affected by it. If the walls and roofs of the buildings are made heavy, it’s also too dangerous in an earthquake (Yön et al., 2020).

1.2.3 POOR FOUNDATION DESIGN
One of the main causes of building failures during earthquakes is inadequate foundation design. Excessive settlement or tilting of the structure due to shallow or weak foundations might result in structural damage (Piancastelli, 2022).

1.2.4 INSUFFICIENT REINFORCEMENT
Structures that are not properly fortified, such as steel or reinforced concrete, are more susceptible to the forces generated by earthquakes. Shear or flexural failures are examples of brittle failure modes resulting from inadequate reinforcing (Li et al., 2019).

1.2.5 INADEQUATE SEISMIC DESIGN CODES
Structures built in areas with inadequate or antiquated seismic design codes are more vulnerable. Using contemporary seismic design guidelines enhances a building's ability to withstand earthquakes (NEHRP, 2021).

1.2.6 SOFT OR WEAK-STOREY DESIGNS
In the case of an earthquake, excessive damage may result from soft or weak story conditions, in which the lower levels are noticeably less robust or stiff than the top stories. The structure may collapse as a result of such designs (Issa et al., 2017).

1.2.7 NON-DUCTILE CONSTRUCTION
Since non-ductile materials and designs cannot dissipate energy or deform without failing, they can fail suddenly during an earthquake. Ductile materials are necessary to absorb earthquake energy (Huang et al., 2021).

1.2.8 INADEQUATE CONNECTION
Weak or inadequately defined connections between structural parts might result in localized failures that eventually cause the building to collapse. Accurate connection information is essential for earthquake resistance (Yakut et al., 2022).

1.2.9 SITE-SPECIFIC GEOTECHNICAL ISSUES
The kind of soil and proximity to fault lines are two local geotechnical factors that can have a big impact on how well a building performs during an earthquake. Ground motion amplification and soil liquefaction may be harmful (Khan et al., 2021).

1.3 TECHNIQUES FOR MAKING STRUCTURES MORE EARTHQUAKE-RESISTANT
Engineers work to design a building that is earthquake-proof by fortifying the structure and reducing the consequences of a potential earthquake. The strategy involves having the building push in the opposite direction from the direction in which earthquakes release energy, which pushes structures in one direction. Here are several methods for strengthening buildings against earthquakes (Bredenoord, 2016).

1.3.1 AN EXTENSIBLE FOUNDATION
To "raise" the building's foundation above the earth and withstand ground forces, a technique known as base isolation is employed. Building a building on top of flexible steel, rubber, and lead pads is known as base isolation. During an earthquake, the isolators vibrate as the base trembles, but the building stays still. Seismic waves are effectively absorbed and prevented from entering the building (Madina, 2022).

1.3.2 OPPOSING FORCES IN CONTRAST TO DAMPENING

If you recognize the type of shock absorbers used in cars, you may be surprised to learn that engineers also use them in earthquake-resistant constructions. Similar to how they function in cars, shock absorbers reduce the force of shockwaves and the strain on the structure. This is accomplished through the employment of vibrational control devices and pendulum power.

This method entails placing dampers at each structural level in between columns and beams. Each damper is made up of a silicone oil-filled cylinder and heads of pistons. The vibrational energy of the structure during an earthquake is moved to the pistons, where the oil is pressed. Next, the vibrations' force is dissipated as heat is produced by the energy's conversion (Khatami et al., 2020).

Pendulum power is another common damping method that is used primarily in skyscrapers. To do this, engineers hang a sizable ball from steel cables that are connected to a hydraulic system at the top of the building. When the building begins to tremble, the ball acts as a pendulum and swings in the opposite direction to stabilize it. Similar to damping, these features are changed to match and offset the building's movement during an earthquake (Shoaib Mirzad, 2020).

1.3.3 PROTECT STRUCTURES FROM VIBRATIONS
Instead of just counteracting pressures, structures may be able to entirely deflect and redirect the energy from earthquakes, according to research methodologies. This

creation dubbed the "seismic invisibility cloak," comprises burying a cloak at least three feet below the building's foundation. It is made out of 100 concentric plastic and concrete rings. Seismic waves penetrate the rings and are forced to go through to the outer rings due to their ease of transit. As a result, they face away from the building and disappear into the earth (Madina, 2022).

2.0 HISTORICAL BACKGROUND

We have taken Quetta (Balochistan, Pakistan) as the earthquake-prone area of Pakistan. On 31st May 1935 in Quetta (British India now Pakistan) a major earthquake of M7.6 destroyed Quetta affecting 71000 people and damaging about 14000 houses. The total number of people dead was between 35000 to 70000 and thousands more people were in the area. The narrow streets in the city had a higher death ratio in contrast the cantonment area was not much damaged due to well-constructed buildings. The Quetta was reconstructed with some rules and engineered ways, and strong materials were used, making the constructions earthquake-proof. According to new planning, the streets were made wider with an improved water supply and sewage systems to ensure quick breakout and approach in case of another earthquake. The geologists and engineers preferred 30 feet tall and squared buildings with quick escape ways. This was the first time to impose the code of seismic buildings. The people protested because the construction code was too costly, but the government insisted the people follow the rules. The code was observed successfully in the earthquake of February 18th, 1955 (about M6) which caused only 12 deaths (Historical Case Study India 1935 / Earthquake, 2018).

3.0 MATERIALS AND METHODS

Some of the engineering materials which are used for the construction of buildings are described below.

3.1 STONE BUILDINGS

Post-earthquake studies show that houses with thick stone or mud walls of about 600 to 1000 mm and roofs with a 150 to 450 mm thick layer of clay prove most dangerous in an earthquake. It showed that the greater the weight of the building is, the more dangerous it is thus, the damage to the structure is a function of its weight. In rural areas, the walls are generally made of mud mixed with dry grass or wheat husk, clay bricks, and stones. The roofs are supported by strong wood bars to overcome the effect of an earthquake. Mud is placed between clay bricks or stones to make its grip strong, and no blank spaces are left between them (Schildkamp et al., 2021).

Figure 2 Stone buildings commonly used in rural areas.

3.2 WOODEN HOUSES

Houses made of wood are tied together with roofs made up of dried plant materials that are lighter such as rice or wheat straws and thatch, supported by a wooden beam. The houses with or without mud plaster were found to be resistant to earthquakes due to their lightweight weight and beam support. Similarly, flat roofs with wooden frames in which roof components are connected with vertical and horizontal beams, are found to be safe during earthquakes. The roof supported by wooden beams prevents inward collapse of the walls resulting safety of natives (Inoue et al., 2023).

Figure 3 Wooden house

3.3 CONCRETE BUILDINGS

In urban areas, the people are high class, and they cannot live in houses made of clay, wood, or stones because it is costly and not easily available. So, buildings with concrete, baked bricks, and cement are made with round and flat steel rods fitted in with concrete roofs. The weight of the roof and walls is kept less as buildings with high weight are dangerous in an earthquake. Maximum beams are given between the walls and the length of the walls is kept short to withstand the earthquake. If the wall is lengthy, the two walls are connected beams with iron rods that hold it tight. Also, square-type buildings are preferred safe as compared to rectangular buildings because it reduces their length and makes them strong (Guri et al., 2022).

Figure 4 Concrete buildings commonly used in urban areas.

3.4 SKELETON SYSTEM

A skeleton system is applied on walls which consists of a steel truss. The walls and roofs are supported by steel columns by holding down the bolts fitted in reinforced cement concrete (RCC) or burnt brick roofs. All the parts of the materials are connected with nuts and bolts to make a single unit. Corrugated Galvanized Iron (CGI) sheets are used in roof coverings which are non-corrosive and strong materials to prevent the buildings from earthquakes. The wind bracings are used on both opposite sides of walls longitudinally to make them strong, rigid, and safe against winds and are also easy to handle (Chen & Qian, 2023).

The skeleton system is also advantageous as it can be completed in multiple stages depending upon the financial resources. Once this system is adopted, it may be used for primary requirements and then for further construction like flooring and joinery, etc.

Figure 5 Plates welded to steel bars in skeleton system.

The buildings constructed with grass, wood, and bamboo are used by the majority of the people in rural areas. It is earthquake-friendly and lightweight but is weak, can easily decay, and is highly combustible due to its organic nature. So, it has a short life and cannot be reused. The quality of the building can be improved by joining the bamboo and wood with wires and insulating them to prevent them from combustion (Chen & Qian, 2023).

One prime example of a structure built using a tried-and-true earthquake-proof skeleton system is Mexico City's Torre Reforma. This tower, which was finished in 2016, is an example of modern earthquake engineering. The Torre Reforma has two structural systems: an exterior steel exoskeleton and a conventional reinforced concrete core. This exoskeleton greatly improves the building's earthquake resilience because it is made to absorb and disperse seismic forces. To ensure that the skyscraper could withstand even the most powerful earthquakes, advanced engineering approaches were used in its construction, which was guided by thorough seismic assessments. The Torre Reforma's success serves as evidence of how well cutting-edge skeletal systems may be used to build earthquake-resistant buildings.

4.0 RESULTS AND DISCUSSION

The results showed that buildings constructed with a good code of construction and in the presence of professionals were stronger and more resistant to earthquakes and other natural disasters. The death ratio was negligible as compared to the past. The reason was using good materials and construction in an engineered way with the help of professionals and technical knowledge. Among the different methods of construction, the skeleton system was found to be more seismic-proof and economical. The steel rods in the walls and CGI in the roofs hold the structure and make it rigid which lowers the effect of an earthquake. This system can be adopted by affluent as well as impoverished people. The system can be adopted in every climate around the world.

A comparative analysis of the various building construction techniques, such as skeleton system buildings, stone structures, timber buildings, and concrete buildings, can offer important insights into their varied properties and suitability for diverse uses. Although it's generally true that the skeleton system is the most effective and earthquake-proof of these construction techniques, it's crucial to comprehend the benefits and drawbacks of each strategy.

4.1 COMPARISON OF DIFFERENT TYPES OF BUILDINGS

4.1.1 STONE BUILDINGS

Advantages: Stone structures are fire-resistant and have a classic aesthetic charm. They function well in areas where there is little seismic activity.
Limitations: Because stone is heavy, it is not as appropriate for use in taller buildings and could not be as earthquake-resistant as more contemporary building techniques.

4.1.2 WOODEN BUILDINGS

Advantages: Wooden structures are inexpensive, lightweight, and ecologically benign. They are effective in seismically moderate to low-risk zones.
Limitations: Given that wood is not as robust as concrete or steel, it might not be appropriate for high-rise structures or areas that are prone to earthquakes.

4.1.3 CONCRETE BUILDINGS

Advantages: Buildings made of concrete are renowned for their strength, resilience to fire, and longevity. Furthermore, they require little upkeep.
Limitations: Although concrete has a certain amount of seismic resistance, a well-designed skeleton system building may be more earthquake-resistant than concrete. In addition, it requires a lot of energy to make and, in some cases, can break.

Table 2Earthquake and its Damage to Buildings

NO.	Building Type	Intensity VII	Intensity VIII	Intensity IX
1	Ordinary bricks and poor half-timbered buildings	Many have small cracks in the walls	Most have large deep cracks. Few collapse partially	Many partial collapse Few collapse completely
2	Well-built wooden buildings	Many have fine cracks	Most have small cracks. Few are deeply cracked	Most have large deep cracks. Few are partially collapsed
3	Mud and stone construction	Most have large deep cracks. Some will partially collapse	Most are partially collapsed. Few collapse completely	Most are completely collapsed

Because of its superior seismic resistance, correctly designed and built skeleton system structures are usually the favored option in earthquake-prone areas. When choosing a construction method, it's crucial to consider other aspects like cost, aesthetics, the impact on the environment, and local building codes. To ensure efficiency and safety, skilled engineering and architectural skills are essential. Each building method has its own unique design and construction requirements.

4.1.4 SKELETON SYSTEM BUILDINGS

Advantages: Buildings with skeleton systems, which are frequently made of steel or reinforced concrete frames, are thought to be the most earthquake-resistant. Because of their ability to disperse seismic forces, they provide better structural performance during earthquakes.
Limitations: They might not have the same aesthetic value as more conventional materials like stone or wood and can be more expensive to construct.

5.0 CONCLUSIONS

An earthquake is the most dangerous natural disaster which shatters thousands of lives and destroys thousands of buildings in a few seconds. It needs special attention to construct buildings, especially in habitable areas. Standard codes and engineering methods are available for the construction of earthquake-proof buildings, but it is not implemented due to a lack of governance and opulent class people in society. The poor people of society do not implement the construction due to a lack of technical knowledge and financial resources.
The practices suggested above can make the constructions earthquake-friendly to some extent. They are not completely earthquake friendly but at least will save some of the lives in the affected areas. This damaged material can be reused in the construction of buildings.

5.1 LIMITATIONS

Only historical earthquake records from two publicly available sources were used in this investigation. To more accurately reflect the recorded seismic events in the region, it will be crucial for future research to gather data from a variety of sources. Additionally, it could be advantageous to obtain some field data from the pertinent local agencies. In addition, other variables can be added to the ones used in this study to see if they have an impact on the model's performance.

5.2 RECOMMENDATIONS

The accuracy evaluation results support the usage of the model provided in this study for both low and high-magnitude earthquake prediction. Furthermore, the relevant authorities may find earthquake prediction systems to be of tremendous assistance. When such a system sounds an alert, controls can be set to activate supplies and stop vital damage-causing systems, such as nuclear power plants and electricity, to prevent fatalities. Subsequent investigations can evaluate the applicability of additional DNN architectures, including CNNs, for earthquake prediction and compare their performance with alternative methods to determine which model is the best. Furthermore, in the context of different seismic locations, the impact of the FD variable on the effectiveness of other modern and traditional methodologies can also be evaluated.

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