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INDIGENOUS EARTHQUAKE-RESISTANT TECHNOLOGIES – AN OVERVIEW

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SUMMARY

Indigenous earthquake-resistant housing technologies have developed in different parts of the world to enable the people to safely withstand earthquakes. These technologies also address other crucial factors such as availability of local construction materials, functionality of the building designs and safety of the occupants from weather extremes. Unfortunately, these technologies are becoming increasingly unpopular due to large-scale induction of modern construction materials and technologies. However, a large proportion of modern buildings in developing countries perform unsatisfactorily during earthquakes due to improper construction. An evaluation of the indigenous earthquake-resistant technologies shows that they follow all the guiding principles of sound earthquake-resistant design and construction practices. Their lack of popularity stems mainly from the absence of modern engineering tools for their design and construction. This paper discusses the key features of the indigenous earthquake-resistant construction technologies and describes the conditions in which they are found ideally suitable for large-scale use in developing countries.

INTRODUCTION

Earthquakes and their disastrous consequences have been instrumental in shaping human history, and gaining knowledge to predict or prevent earthquakes disasters has been an integral part of human quest for knowledge since earliest times. Available information shows that several ancient civilizations developed legends to rationalize earthquake disasters and to link their occurrence with deviant or undesirable human behavior. For example, the ancient Japanese believed that the earthquakes were caused due to wriggling of a giant catfish that kept the ground afloat. This catfish could be kept still only by god Kashima, which kept the catfish pinned except when the demons became strong enough to disturb Kashima.

The human attempts to overcome the disastrous consequences of earthquakes have included: (1) spiritual efforts through prayers and appeasement of gods, (2) scientific efforts through identification of

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earthquake-prone areas and prediction of earthquakes, and (3) engineering efforts through development of earthquake-resistant construction technologies. The scientific quest of predicting earthquakes still continues in modern times with only very limited success. However, several ancient civilizations were able to identify areas prone to repeated large earthquakes.

The most remarkable achievement of ancient cultures and civilizations has been the development of several different indigenous earthquake-resistant construction technologies. The effectiveness of these traditional technologies has been clearly brought out during recent earthquake disasters. For example, during the Bhuj earthquake in India in 2001, a large number of traditional constructions experience low level of damage while their neighboring modern buildings suffered extensive damage and loss of life. Similar experiences have also been repeated in the Marmara earthquakes in Turkey in 1999, the Killari earthquake in India in 1993 and several other recent earthquakes. These clearly show that the local traditional construction practice had adapted earthquake-resistant technologies, which are now being lost due to the induction of modern materials and construction techniques in these areas without addressing the seismic safety of modern constructions.

In traditional constructions, the architectural forms, choice of building materials and structural configurations have typically evolved from day-to-day living considerations. These were required to satisfy the needs of normal lifestyles and also adequately shield the occupants from extreme weather conditions (heat, cold, flooding etc.) and external threats. The weather extremes are an annual feature and their maximum can be effectively assessed based on the accumulated memory of a few generations. The development of housing technology addressing extreme weather conditions can therefore be based on the living memory of the people spanning two or three generations. The earthquake disasters, on the other hand, have long return periods (several years to several dozen decades) even in the highly earthquake-prone areas of the world. The normal housing technology evolution process is therefore not expected to result in widespread incorporation of earthquake-resistant technologies, which cannot be based on living memory of a few generations, except through systematic collection and processing of knowledge spanning over several generations. The evolution of earthquake-resistant construction practice therefore demonstrates that an effective process for collecting and incorporating scientific knowledge existed in these cultures and civilizations.

The modern construction practice in most countries is governed through standard codes and specifications. These standards specify and control all aspects of analysis, design and construction of structures. Most standards are based on the knowledge of seismology and earthquake engineering and are able to incorporate advanced concepts and developments of these fields. The codes and standards in both developing and developed countries are similar in their specifications since they all use the same worldwide knowledge of construction materials and structural behavior. However, the performance of modern buildings in developed countries has been very different from those in developing countries for similar earthquake events. While most buildings in developed countries perform as per the specifications, the performance of similar buildings in developing countries where modern standards are in use have been found to be highly deficient. The poor performance of building stock during earthquakes in several developing countries indicate that the basic problem of modern construction may not be in the technical adequacy of the standards but in their implementation and compliance systems. This also clearly illustrates the inability of the engineering profession to follow and enforce the modern standards.

The traditional earthquake-resistant construction technologies are empirical and their specifications are based on thumb rules. As a result, the critical elements from earthquake-resistance considerations are not always understood by the practitioners of this trade. The empirical nature of these construction technologies has also inhibited their standardization, which is a prerequisite for all modern construction practices. However, good performance of traditional earthquake-resistant constructions in regions where modern construction technologies have performed unsatisfactorily provide important lessons for seismic safety of the economically weaker sections of the society. It is generally found that the owners of buildings constructed with modern materials and technology in developing countries belong to the socially and economically more affluent classes. On the other hand, the economically weaker sections of the society are more likely to use traditional construction materials due to its lower cost. Since most indigenous earthquake-resistant construction technologies have relatively low cost, the use of these provide an exciting opportunity for safer housing for the economically weaker sections of society who are otherwise forced to live in weak constructions.

The indigenous earthquake resistant construction technologies prevalent in different parts of the world are highly variable in their choice of materials and construction techniques. These technologies can be grouped together based on their critical elements providing resistance against earthquakes. The indigenous earthquake-resistant construction techniques may employ more than one of these elements. The details are discussed in the following sections.

ELEMENTS OF INDIGENOUS EARTHQUAKE-RESISTANT CONSTRUCTION TECHNOLOGIES

All traditional earthquake-resistant construction technologies provide the building with the capacity to withstand large earthquake forces without catastrophic collapse. From structural behavior consideration, these technologies can be divided into the following general categories:

1. *Construction technologies using ductile construction materials* – such as building made of timber and bamboo.
2. *Construction technologies using robust architectural forms* – such as buildings with symmetric plan and elevation.
3. *Construction technologies using resilient structural configuration* – such as buildings with bands and braces.
4. *Construction technologies reducing seismic forces* – such as through use of light-weight non-structural members.

Ductile Construction Materials

The traditional constructions in several earthquake-prone regions of the world make extensive use of ductile materials such as timber and bamboo. Traditional timber construction practice has been found to be prevalent from equatorial to temperate regions while bamboo construction practice is more prevalent in equatorial and tropical regions. These materials can be highly ductile and have the ability to undergo large deformations without failure. This property makes these materials ideal for construction of earthquake-resistant houses that need to withstand intense ground motions. The earthquake-resistant behavior of these constructions typically depends on the ability of the connections to withstand the demands imposed due to large deformations of the structural elements. The connection systems for traditional constructions using ductile materials therefore play a key role in determining the earthquake resistance of these constructions. For example, very detailed connection system for timber constructions have been developed in China that enable them to construct large earthquake-resistant structures that have lasted for hundreds of years. Other construction practices using bamboo or a combination of bamboo and timber permit construction of low-cost buildings that are highly earthquake-resistant and also satisfy other functional requirements. These construction technologies have been widely used in different parts of the world. Such constructions have shown very good performance during past earthquakes.

Since timber and bamboo are both prone to decay, the earthquake resistance of buildings made from these materials may be severely compromised due to weathering if they are not properly maintained. Most earthquake-resistant constructions of these materials are therefore used for buildings that are not required to be very durable. Some earthquake-resistant constructions using treated timber have lasted for several hundred years due to incorporation of measures inhibiting decay and loss of strength with time.

Robust Architectural Forms

Buildings that have a regular geometric shape, are symmetric in plan, and have uniform elevation generally have greater seismic resistance than irregular buildings. Buildings with simple regular geometric shape such as a rectangle do not have re-entrant corners that may experience stress concentration under earthquake loads. Symmetry of plan ensures that the earthquake-resistant features are equally distributed in the building and the earthquake-resistance of the building is similar in all directions giving it the ability to equally resist earthquakes from any directions. The symmetric plans ensures that the building center of mass and center of stiffness are coincidental and the effects of torsion are minimized. Buildings with uniform elevation also generally have earthquake-resisting elements uniformly distributed and do not experience concentration of forces in a particular location of the building. All these properties are helpful in improving the earthquake resistance of the building.

The indigenous earthquake-resistant construction practice in several parts of the world have developed highly symmetric building plans that also satisfy the functional requirements of the people. Rectangular plans and other configurations without large re-entrant corners are commonly used in these constructions. The load resisting elements of these buildings are uniformly distributed throughout the structure providing uniform stiffness.

In some earthquake-prone areas such as the Kutch region of India, cylindrical plan one-story buildings are used. These buildings are also symmetric, and the configuration provides high resistance to earthquake forces. Cylindrical shape also provides these structures with high degree of resistance to wind forces since the area where these constructions are used are highly cyclone-prone. Cylindrical one-room buildings are not very convenient to use since most work units are rectangular in shape. In order to still use cylindrical building shapes, the Bhonga architecture has developed in the Kutch region wherein multiple cylindrical units (Bhongas) are used along with their intermediate spaces so as to fulfill the functional requirements and also provide the necessary privacy.

Resilient Structural Configurations

Structures with well-distributed and redundant load resisting systems perform very well under earthquake excitations. Several indigenous earthquake resistant construction technologies that satisfy this requirement have developed. The earthquake forces are resisted through walls or through frame systems. In constructions that use walls for providing lateral stiffness, the use of local materials ensures that the walls are not very strong. However, the walls are tied together using bands at different levels so that they behave as an integral unit. This enables the distribution of inertia forces during earthquakes to all the walls resulting in high seismic resistance. In some earthquake-resistant construction practice found in Kashmir in India, very small dressed stone masonry pieces are interlocked together without mortar to form the wall. During the earthquake, these pieces can vibrate rubbing against each other thereby dissipating the earthquake energy and increasing the earthquake resistance.

Several different types of indigenous frame structural systems also provide high seismic resistance. Timber or bamboo constructions with diagonal braces have been used in different parts of the world. Special connection details are used in these constructions to connect the braces to the frame to ensure integral action during earthquake loading. The simplest bracing systems are found in traditional Turkish constructions that use diagonal timber brace with timber frame. The Assam type houses in India also use diagonal braces. Other more complex structural systems include the Bahareque in Central America, which is a combination of timber frame with bamboo ties.

Reduction of Seismic Forces

The inertia forces that develop during an earthquake are directly proportional to the mass of the building. The traditional construction practice in Japan uses partition walls of very low weight to reduce the seismic forces. Due to the functional requirements, these earthquake-resistant buildings may have heavy exterior walls and roofs but the internal walls consist of materials of relatively low weight. The use of these internal walls results in reduced privacy that needs to be culturally acceptable and may be unique to Japan. Other instances of indigenous earthquake-resistant construction practice that reduce the seismic forces through similar reduction in mass are not in widespread use.

Most earthquake-resistant indigenous constructions combine several of these elements to provide the necessary seismic resistance. While simple architectural forms are almost universally used in indigenous constructions, most also use various structural methods for improving the lateral resistance of the buildings. Several earthquake-resistant construction techniques also use the advantages of timber and bamboo. From weather safety considerations, stone and brick masonry constructions are also popular in different parts of the world. These have been used for earthquake-resistant buildings by incorporating desirable architectural forms and structural configurations.

RESEARCH, DEVELOPMENT AND IMPLEMENTATION OF INDIGENOUS TECHNOLOGIES

There is considerable recent interest in research and development related to indigenous earthquake-resistant technologies that are found in different parts of the world. Most research activities are, however, limited to documentation of the earthquake-resistant features. Only very limited research effort focuses on developing quantitative understanding of behavior of these structures so that the technologies can be further improved and analytical methods for their use can be developed. Since indigenous technologies use local materials whose properties are highly variable, there is considerable difficulty in quantifying their engineering characteristics. Analysis and design tools are also difficult to develop in the absence of well-defined material properties. Most research has therefore focused on development of prescriptive design and construction guidelines.

The absence of well-developed analytical design tools makes these technologies appear less “modern” and more prone to unsatisfactory performance due to uncertainty in the material properties. However, the use of traditional local materials results in lower cost of these constructions. In areas with high cost sensitivity, these constructions can be used to provide a “minimum” level of seismic safety at significantly lower cost compared to those of RCC or steel.

In developing countries where modern construction technologies performed poorly during past earthquakes, the increase in overall level of earthquake resistance of the building stock requires retraining of the entire construction industry: the architect, the engineers, the contractors, the skilled workers, the semi-skilled workers and the unskilled workers. This is due to the integrated nature of construction projects in which all role-players have critical responsibilities. The retraining, if and when implemented, provides immense benefit to the economically affluent sections of the society. However, the economically weaker sections of the society are unlikely to benefit significantly due to their inability to afford engineered constructions.

Under this situation, the indigenous earthquake resistant technologies can be proposed for the use of economically weaker sections. These constructions cost significantly lower than those using modern construction materials. Their use also generally involves only the skilled, the semi-skilled and the unskilled workers. These can be suitably trained to ensure that the buildings provide the minimum level of seismic safety.

This strategy has been used in several parts of the world following devastating earthquakes. In some areas such as the Kutch region of India and in Turkey, indigenous earthquake-resistant technologies that already existed but were not used due to widespread induction of modern construction techniques have been revitalized. In other areas such as Killari in India and in Iran, earthquake-resistant construction technologies based on locally available materials were inducted from other earthquake-prone regions. In all such situations, the use of local materials and indigenous earthquake-resistant technologies has been found to provide a cost-effective means for sustainable reconstruction of a large number of buildings.

DISCUSSIONS AND CONCLUSIONS

This paper provides a brief description of the development of indigenous earthquake-resistant technologies in different parts of the world. The paper describes the circumstances leading to their development and highlights the ability of ancient cultures and civilizations to collect and process scientific knowledge spanning several generations.

The paper also describes the key features of all earthquake-resistant indigenous construction technologies. It is seen that the essential elements of all the technologies can be categorized into four classes: (1) Ductile construction materials, (2) Robust architectural forms, (3) Resilient structural configurations, and (4) Reduction of seismic forces. Most earthquake-resistant construction technologies include multiple elements to provide the required resistance. It is also seen that modern analytical design procedures cannot be extended to the use of indigenous construction technologies due to uncertainties in material properties. However, prescriptive design and construction procedures based on current knowledge can be developed so as to provide the minimum level of safety to these constructions.

It is also seen that the use of indigenous earthquake-resistant construction technologies provides an excellent opportunity for large-scale construction of earthquake-resistant housing in developing countries at relatively low cost. However, there is a need to greatly expand the research and development activities in this field to further improve these technologies and make them acceptable as modern construction techniques.

BIBLIOGRAPHY

1. Earthquake Engineering Research Institute (EERI). World Housing Encyclopedia (www.world-housing.net).
2. Erdik, M. "Report on the Turkish earthquake of October 30, 1983." Earthquake Spectra 1984; 1:151-172.
3. Homan, J, and Eastwood, WJ. "The 17 August 1999 Kocaeli (Izmit) earthquakes: Historical records and seismic culture." Earthquake Spectra 2001; 17: 617-634.
4. Langenbach, R. "Intuitions from the past: What we can learn from traditional construction in seismic areas." International Conference: Earthquake Safe: Lessons to be Learnt from Traditional Constructions, Istanbul, Turkey 2000.
5. Mendes-Victor, L, Ferrigni, F, Mauro, A, Pierotti, P, Helly, B, Rideaud A. Ancient Buildings and Earthquakes, European University Center and Council of Europe 1997.
6. Ofori, G. "Construction industry development for disaster prevention and response." Improving Post-Disaster Reconstruction in Developing Countries, Montreal, Canada 2002.
7. Shiping, H. "The earthquake-resistant properties of Chinese traditional architecture." Earthquake Spectra 1991; 3: 355-389.
8. Sinha, R, Shaw, R, Goyal, A, Choudhary, MD, Jaiswal, K, Saita, J, Arai, H, Pribadi, K, and Arya, AS. The Bhuj Earthquake of January 26, 2001, Indian Institute of Technology Bombay and Earthquake Disaster Mitigation Research Centre, Miki, Japan (Joint Publication) 2001.
9. United Nations Center for Human Settlements (Habitat). Earth Construction Technology, Habitat 1992.