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COMPATIBILITY OF CONSTRUCTION MATERIALS IN DIFFERENT GEO-CLIMATIC REGIONS OF INDIA FOR EARTHQUAKE SAFETY

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Abstract

India is a country which is prone to earthquakes. Many great earthquakes of the world have occurred in India, but still safe earthquake construction practices are not popular yet. This is mainly due to lack of awareness regarding earthquake problems and also earthquake safety features of buildings. On the other hand, India is a country with many diversified building technologies where there is a large variation in selection of building materials and building technologies. Over the ages, building materials and technologies were linked to the geo-climatic conditions of the area and the same is evident from census data of the country. However, during past earthquakes, many buildings collapsed due to the lack of earthquake resistant features in these buildings, resulting in huge life loss. This paper is an attempt to identify the critical earthquake resistant elements in each building typology which is popular in a given region. The same is demonstrated by taking two building typologies i.e., framed buildings and load bearing structures in four different regions i.e., hilly region, plain region, snowfall region and heavy rainfall region. From the above, it is clear that each housing typology can be made earthquake resistant by understanding the role of critical elements and by not deviating from standard design which is safe as well as compatible with geo-climatic conditions of the region.

Keywords: Earthquake safety; Traditional buildings; Materials; geo-climatic condition;

1. Introduction

In India, most house construction is done by individual homeowners themselves, and in many cases by masons acting as "self-styled" contractors; often, all this is without the involvement of an engineer or architect. Consequently, the expected knowledge base for planning and design is not available to make these houses earthquake resistant, and therefore the level of risk associated with such construction is not known. In the last two decades, a number of earthquakes in the country have caused significant loss of live and property. A large part of this loss is attributed to the type of housing typologies in practice in the country. For example, the relatively smaller size 1993 M6.4 Killari (Maharashtra, India) earthquake alone caused about 7,928 deaths; this colossal loss of life is attributed directly due to collapse of houses built with random rubble stone masonry walls in mud mortar topped with heavy wood plant and joist roof overlaid with about 600mm of mud.

This paper is an attempt to classify the building typologies according to Architecture, Structural configuration, construction technology, materials used, etc. Also, it is proposed to understand the earthquake safety features in each typology which is popular in a given region. The same is demonstrated by taking two building typologies i.e., framed buildings and load bearing structures in four different regions i.e., hilly region, plain region, snowfall region and heavy rainfall region. From the above, it is clear that each housing typology can be made earthquake resistant by understanding the role of critical elements and by not deviating from standard design which is safe as well as compatible with geo-climatic conditions of the region.

2. Housing in India

Presently, India is home for 1.2 about billion people. Over the last six decades, there has been a great shift of population from rural to urban areas, thus increasing the densities of population in urban areas (Table 2). This suggests that about 300 million houses are necessary to house them. According to National Housing Policy 2007 [2], the housing shortage is estimated to be about 25 million. And according to 2011 Census [3], Indian urban population constitutes 32.25%. However, it is increasing at an alarming rate of 4% per year. The number and proportion of cities with a population of one million or more has grown significantly in recent decades. From 12 in 1981 with 26.8% share of the total population, the number of million-plus cities has increased to 35 in 2001 with 37% share of the total urban population. In addition housing shortage is already higher in urban areas, notwithstanding the ever increasing population densities. Figure 4 shows the district-wise spatial distribution of population density in India. Population in India is distributed unevenly with minimum of 50 persons per km^2 in some districts and up to 14000 persons per km^2 in some other districts.

In India, numerous housing typologies are practiced (Table 2). Further, each of these typologies has many sub-typologies. In the early years after Independence, artisans were easily available with hands-on experience of having constructed houses of traditional typologies. They had skills and know-how on traditional technologies of house construction with different materials, e.g., burnt clay brick walls in mud/lime mortar, clay tile roofing on wooden rafters, and wooden doors and windows. These technologies were cost effective and were especially suited to regional atmospheric conditions. These houses stood for decades, and were environment and energy friendly. But, over the last two decades, many new materials and building technologies were introduced in urban areas, which found their way in rural areas. These technologies were not suitable to both urban and rural areas for resisting the prevalent hazards. In many instances, advanced technologies were employed in rural areas with little or no engineering inputs. Most critical aspect of housing is that all rural housing and some urban housing is self-built by the citizens.

Table 1 : Housing stock in India [3~7]

Year of Census	*Number of Houses*	*Increase (%)*		
		From previous decade	*Cumulative since 1961*	*Decadal Increment since 1961*
1961	10,98,00,000	-	-	-
1971	13,70,00,000	24.80	24.77	24.77
1981	17,08,00,000	24.67	55.56	30.79
1991	21,16,00,000	23.85	92.71	37.15
2001	25,68,00,000	21.35	133.88	41.17
2011	30,48,82,448	18.69	177.67	43.79

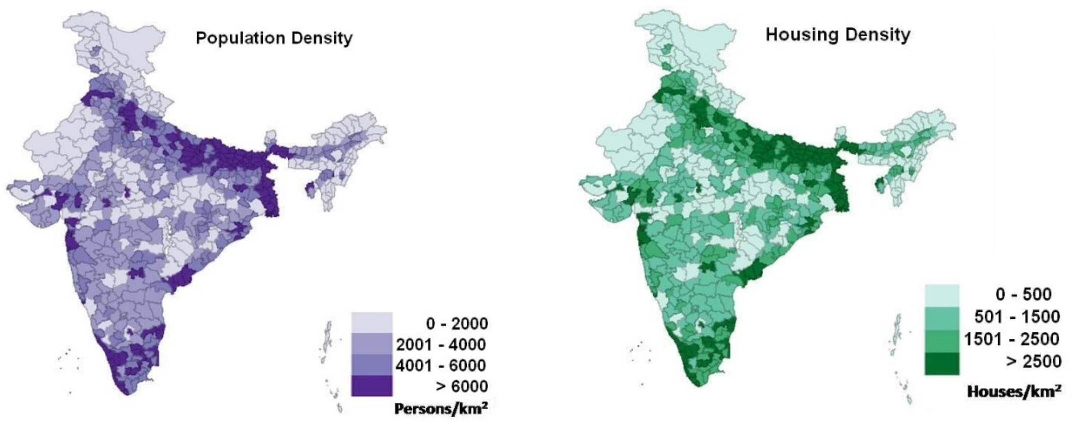

Figure : Population and Housing Densities [8]

The choice of materials used in construction throughout the country is shown in Table 4; the choice for natural materials is high. In the choice of roofing material, around 75% of houses in rural areas use natural and locally available material for construction; in the remaining 25% houses cement-based materials are used. On the contrary, in urban areas, cement-based materials are upto 50% and naturally available material the remaining 50%. For the wall, 90% of houses use natural material only, But, in urban areas, it is up to 10%.

Table 2: Housing with Roof and Wall Material from 2011 Census of India

S.No	**Item**	**Number of Houses (Census 2011)**					
		Rural	**%**	**Urban**	**%**	**India**	**%**
	Roof Material						
1	Grass/Thatch/Bamboo/	33,126,01	19.9	3,611,906	4.60	36,737,922	15.02
2	Plastic/ Polythene	1,047,533	0.63	500,251	0.64	1,547,784	0.63

3	Hand made Tiles	30,386,08	18.2	4,863,880	6.20	35,249,965	14.41
4	Machine made Tiles	17,307,19	10.4	5,503,054	7.01	22,810,252	9.32
5	Burnt Brick	11,990,02	7.22	4,231,255	5.39	16,221,284	6.63
6	Stone/Slate		8.87	6,222,441	7.93	20,968,579	8.57
7	G.I./Metal/Asbestos	26,522,85	15.9	12,476,710	15.9	38,999,562	15.94
8	Concrete		18.3	40,764,887	51.9	71,188,588	29.10
9	Any other	607,051	0.37	310,595	0.40	917,646	0.38
	Grand Total		**100.**	**78,484,979**	**100.**		**100.0**
	Wall Material						
1	Grass/thatch/bamboo etc.		12.7		2.57	28,947,594	9.49
2	Plastic/ Polythene	762,256	0.37	335,575	0.34	1,097,831	0.36
3	Mud/unburnt brick		28.2		8.26	66,449,827	21.80
4	Wood		1.03	648,929	0.66	2,781,271	0.91
5	G.I./metal/asbestos		0.61		1.08	2,331,869	0.76
6	Burnt brick		40.4		64.0	146,545,805	48.07
7	Stone	28,685,7	13.8	1479714	15.0	43,482,9	14.26
8	Concrete	3,699,096	1.79		7.41	10,983,679	3.60
9	Any other	1,648,466	0.80	613,174	0.62	2,261,640	0.74
	Grand Total	**206,563,6**	**100.**	**98,318,758**	**100.**	**304,882,448**	**100.0**

Performance of Building during Past Earthquake Disasters

Earthquake vulnerability of a house is the amount of expected damage induced to it by a certain level of earthquake intensity. The earthquake performances of the buildings, especially in the last three decades (Table), indicate around 40,000 human fatalities caused primarily by collapse of buildings. Except for Killari earthquake, all other events occurred in known moderate to high seismic zones. Damage caused to these buildings

is unreasonably high compared to any other country for similar level of ground shaking. Serious departures are observed especially in performance of RC buildings. During the 2001 Bhuj earthquake, they collapsed at an intensity of shaking of VII, when MSK scale expects them to collapse only after intensity IX of ground shaking. Thus, there is urgent need to understand the housing risk in the country to minimize the future losses of life and property.

Table 3: Human fatalities during past earthquake events [9]

Year	*Location*	*Casualties*	*Buildings Collapsed*
1988	Bihar	1,004	2,50,000
1991	Uttarkashi	768	42,400
1993	Killari	8,000	30,000
1997	Jabalpur	38	8,546
1999	Chamoli	100	2,595
2001	Bhuj	13,805	2,31,000
2004	Sumatra	10,805	NA
2005	Kashmir	~1,500	4,50,000
2006	Sikkim	2	NA
2011	Sikkim	111	NA
2013	Doda	1	NA
2016	Manipur	10	NA

Housing is a major contributor to losses, both life and property, during earthquakes. The challenge is grave in India, which has moderate-to-severe seismic hazard over about 60% of India's land area. This is compounded by low perception of risk and therefore the abysmally low or even absent preparedness. Many communities in earthquake regions are far from recognizing the problem that safe housing is critical to their sustainable development. These communities need to be supported in reducing earthquake risk to their housing. Large amount of technical information on earthquake safe constructions is available within the world technical community and also in public domain (e.g., www.world-housing.net). But, this knowledge currently is yet to reach communities that are (a) desirous of implementing housing projects, and (b) required to implement safer housing to reduce earthquake risk in future. The available literature may not always be applicable to specific local housing typologies Interface documents and interface working groups need to play a more proactive role across the world to reduce the earthquake risk to housing. Through this project it is proposed to develop Indian Housing Encyclopedia which provides technically sound and sustainable solutions on making earthquake safe houses across India.

3. Case Studies

3.1. Plain Region

A plain is sweeping landmass that generally does not change much in elevation. The regions in India which fall under this category are Punjab, Uttar Pradesh, West Bengal, Bihar, Haryana, Assam. The houses in these regions have predominantly been constructed with the use of Bricks and Stone.

There are two types of houses in this category

1. Brick Panel House
2. Stone Patti House

3.1.1. Brick Panel House

These buildings are used all over the northern part of India. Very common in rural,sub-urban and urban areas. Brick Masonry walls are used for the construction of these buildings, which are either sun- dried of fired bricks. Fired bricks ar epreferred over sun-dried bricks as the durability of the latter is a bit less when compared to the former.these bricks are used with mud or cement mortar. Moreover, the preparation of the material is easily done by the local labour. The material is also locally available and affordable by all the classes of the society.

The structural system is mainly gravity-load bearing system. The load from the roof is transferred to the unreinforce brick masonry walls and also to the foundation.

The lateral load- resisting system is unreinforced masonry walls. The walls have a very low resistance to forces which are out of the plane. In most cases, there is no proper connection between the roof and walls.

Fig 2: Brick Panel House

Fig 3: Stone Patti House

These type of buildings can be made earthquake resistant by providing a seismic band and lintel level and also at roof level.

3.1.2.Stone Patti House

It is a traditional method of construction in Rajasthan. The natural stones available locally are dressed manually and are laid to create walls. As the thickness of the walls will be more, it gives thermal comfort inside the building and due to which energy consumption is less. The process of construction is labour intensive and promotes local economy. Window openings are smaller to protect the severe heat from outside. Small stone slabs are fixed as Stone lintels instead of using of RCC. No usage of steel or concrete for the lintels or for the slab. In this region earthquake threat is less and hence structure has little earthquake resistance features. However, the building can be made earthquake resistant by keeping key stones and a lintel band.

3.2.Hilly Region

3.2.1. Mud Block Structure

Mud is an economical and functional. It is easy to work with and is really useful in humid and hot climates. It is used abundantly as it found everywhere and when compaared to the other construction materials like concrete, stone. Mud is a very good material which affects the environment in a good way when compared to the other materials. It is helpful in solving environmental problems and problema related to energy. Very less fossil energy is consumed in mud construction. Recycling of mud also does not need fossil fuel. The abundance of soil also makes it affordable to all the classees of the society.

The main structural elements are mud walls which carry the load of the roofing. The vertical load resisting system is earthen walls. Mud walls carry the gravity loads due to the roof weight and transmit them to the ground. They are the most susceptible to excessive rainfall, which frequently causes the washing away of the mud from the wall.

The lateral load resisting system also happens to be the earthen walls itself in these mud block structures. The walls dont have any additional support system to deal with any out of the plane forces. Which is the reason for the vulnerability of the buildings during earthquakes. For making these buidlings earthquake resistant it is required to keep mesh all around the building which increase lateral resistant against earthquake shaking.

Fig 4: Mud House

Fig 5: Laterite Stone House

3.2.2.Laterite Stone Construction

Laterite Stone is abundantly available local material all over South India from coast-to-coast. The main feature of these houses are affordability and durability. These houses have a aesthetic look. The foundation of these houses is laid with random rubble Stone masonry with locally available materials. However, the lateral load resistance of these house very low and at the same time the geological is also not very much prone to earthquake events. Shear locking arrangement can be done or mini RC columns can be inserted in the walls for making earthquake resistant.

Fig 6: Wattle and daub House

3.2.3.Wattle and Daub Houses

Wattle and daub house is done by the creation of a frame. Two of the most common frameworks are close studding and parallel bracing.

The materials used in this construction are Wood, cane and bamboo, wattle panels, daub, Plastering. All the materials listed above are quite affordable and long lasting.this particular method of construction is historically proven. Therefore the failure possibilities and causes are also well known. The fact that these structures do not cause harm to the environment makes them even more functional in these hilly regions, where retaining the beauty of the evironment is a must.

This structure is a framed structure where the load of the building is mostly upon the beams and columns. The frame should provide the correct detailing necessary to accept and hold the staves of the wattle panel. Two of te most common frameworks are close studding and parallel bracing. Close studding creates narrow spacing between the timbers and allows for support of the wattle. Parallel bracing uses diagonal bracing to offer support to the wattle. The configuration of structure itself is robust for earthquake resistance.

3.3. Heavy Rainfall Region

Heavy rainfalls are those in which the precipitation rate of rainfall is greater than 7.6 mm (0.30 in) per hour, or between 10 mm (0.39 in) and 50 mm (2.0 in) per hour. The regions in which such rainfalls occur are known as heavy rainfall regions

3.3.1. Bamboo House

Bamboo has been used since a long time as a construction material for houses for its unique property. This material is light at the same time it is very strong and durable as well. With the rise of Concrete, Wood and Steel as primary construction materials, bamboo has been neglected as a crucial construction material. It is very surprising to know that more than a billion peoople are still dwellling in bamboo houses, which explains us the accesibility and affordability of this material all across the globe.

The walls of these structures are highly flexible and have a good tensile strength which makes them earthquake resistant, and in case of collapse, their low weight causes less damage to people and property. The roof of these kind of structures must be as light as posible, which reduces the risk of casualities in the event of roof collapse . A simple couple roof is sufficient.

It is a heavily recommended material due to its contribution to the environment. It is resistant to earthquakes beacuse it is usually resistant to shock and has a supple of flexible nature.

Fig 7: Bamboo House

Fig 8: Coir Composite House

3.3.2. Coir Composite Structure

Coir or coconut fibre is a naturl fibre extracted from the husk of coconut. Coir is the fibrous material found between te hard , internal Shell and outer coat of a coconut. Coir composites have high strength and stiffness. They are also durable, fatigue resistant and corrosión resistant. It is also earthquake resistant due to its capability to absorb much elastic energy. Another advantage of theis coir is that it never shrinks,crack sor produces crust and is completely environment friendly. These structures can be mainly found in the North-Eastern States and Kerala. As, in these regions the cultivation of coconut is extensively practiced.

4. Conclusions

India is a earthquake prone country and it has experienced significant losses during past events. Lot of life loss has taken place due to lack of awareness on earthquake resistant features of buildings. Many new technologies have come but they are catering to the requirements of reinforced concrete buildings and steel buildings. This paper has addressed the needs of particularly the medium to low income group houses which are prevalent in rural and semi-urban areas. Three different geological areas were selected and typical building types in those areas were analysed from the point of view of earthquake safety. Later, suggestion were provided for each of the building typology.

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