Seismic Vulnerability Assessment of Building Types in India

Technical Document (Tech-Doc) on Typology of Buildings in India

by

Seismic Vulnerability Assessment Project Group of

IIT Bombay

IIT Guwahati

IIT Kharagpur

IIT Madras

IIT Roorkee

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Seismic Vulnerability Assessment Project Group, consisting of the following authors, has contributed to the Tech-Doc:

IIT Bombay

Mahendra Meena

Rohan Shinde

Ashish Sapre

Ravi Sinha

Alok Goyal

IIT Madras

Arun Menon

A Meher Prasad

Devdas Menon

CVR Murty

Deepti R Krrishnan

N Uma

IIT Guwahati

SK Deb

Kaustubh Dasgupta

Hemant B Kaushik

IIT Roorkee

Yogendra Singh

DK Paul

Putul Haldar

Aditya Rahul

Ankita Sood

IIT Kharagpur

Nirjhar Dhang

Sushanta Chakrabarty

Arghya Deb

Table of Contents

List of Tables

Abstract

The past few decades have witnessed an increase in the number of damaging earthquakes in India, with nine damaging earthquakes occurring during the last two decades itself. The vast extent of damage and the consequent loss of life associated with these events reflect the poor construction practice in India. Before the 2001 Bhuj earthquake, constructions with poor seismic resistance were assumed to be a feature of non-urban areas, with urban structures considered safer due to the use of engineering knowledge and modern construction materials. However, this earthquake shattered the myth of urban seismic safety through widespread damage to modern buildings. The low awareness among the general public towards structural safety and the inability of regulatory bodies and technical professionals in maintaining quality standards in constructions has created an urgent need to educate the leaders, public, city planners, architects and the engineering professional about the consequences of earthquakes.

There is thus a need to develop standard building typology catalogues of prevalent construction types in India, and to further determine the seismic vulnerability of each class of building in the catalogue. When classes of buildings are considered for risk assessment, the vulnerability can be established in terms of the structural characteristics, and suitable modifiers to the vulnerability function can be established in terms of the geometrical characteristics. Since the construction practices vary in different parts of the country even when using the same construction material, the vulnerability function of different buildings in the typology catalogue will need to be developed for each region separately.

This report presents a summary of the building typologies used or proposed in different parts of the world. The report presents an analysis of these typologies to assess their suitability for India. Based on this assessment, the building typology for use in India has been presented in the report. The proposed building typology is hierarchical, and considers material of construction, structural system, structural irregularities, building height, code compliance and level of maintenance. The building typology catalogue is also developed in a format that is amenable to database management and use of portable computing devices for field data collection.

Chapter 1 Introduction

1.1 General

India faces threats from a large number of natural hazards such as earthquakes, floods, droughts, landslides, cyclones and tsunamis. During the period 1990 to 2010, India experienced 9 damaging earthquakes that have resulted in over 30,000 deaths and caused enormous damage to property, assets and infrastructure. In many cases buildings and structures have proven inadequate to resist earthquake forces and the failure of these can be held responsible for most of the resulting human fatalities. It is also evident from past fatal earthquakes around the world that the existence of vulnerable buildings in high intensity areas has in most cases controlled the total human losses (Jaiswal and Wald, 2008). Understanding the causes of such damage and means to reduce risk; demands effective participation of the scientific and engineering community. The detailed assessment of damage after past earthquakes in our country shows that both non-engineered and engineered buildings suffer extensive structural damage (for example, Sinha et al., 2001). It is also found that even the non-engineered constructions sometimes possess the required resistance to earthquake ground motions (for example, the Assam-type traditional housing in North-Eastern states and the Dhajji-Diwari buildings in Kashmir have good earthquake resistance). Recent earthquakes, such as the 2001 Bhuj earthquake that had followed the damaging Anjar earthquake in 1957 in the same area, have shown that the vulnerability of the constructions were not reduced due to the experiences from the 1957 earthquake. As a result, the same tragic lessons had to be re-learnt in 2001 as during 1957 (Sinha et al., 2001).

In order to predict the likely impact of an earthquake on the built environment in any part of the country, it is essential to know the seismic vulnerability of the built environment on the affected areas. This information depends on the structural systems of the buildings to resist vertical and lateral loads, performance of similar buildings in past earthquakes, and engineering standards adopted during construction. The assessment of likely impact also depends on the location and distribution of vulnerable building stock in the affected areas.

Very limited data currently exists in our country to quantify the building stock and their seismic vulnerability in different parts of the country. The Housing Census data collected every decade compiles information on the construction materials used for walls, floor and ceiling of dwellings. However, this information is technically very difficult to relate to the construction materials used for buildings as a whole due to the nature of data collection that separates out information regarding walls, floor and ceiling so that their combination for buildings is not reported. Even where such information is available based on detailed field surveys, the use of construction materials has not been related to the seismic vulnerability of the buildings. As a result, the technical information on building constructions cannot be fully used for earthquake risk management strategies and programs.

1.2 Disaster Risk Management for Earthquake

The country has initiated several programs from time to time to manage disasters, as well as to mitigate their adverse impacts. The effectiveness of programs related to earthquake risk mitigation is difficult to evaluate due to the absence of tools that can provide consequence analysis. The consequence analysis is carried out using scientifically valid earthquake damage scenarios. These earthquake damage scenarios, if available for different earthquake-prone parts of the country, can also be invaluable for advocacy of seismic safety and for disaster management. The disaster scenario information can be used to sensitise the various stakeholders regarding the risk and the potential consequences of earthquakes. The information can thus overcome some of the limitations due to the absence of earthquake disaster memory in society. The disaster scenario can also help in identifying the most vulnerable areas and population groups that will require special attention in the aftermath of a damaging earthquake.

The pros and cons of various disaster management interventions can also be evaluated using earthquake disaster scenario tools by simulating the effectiveness of these measures in reducing losses over time. The use of disaster scenarios is very useful for both urban and rural areas. Their use for effective disaster management planning is essential in urban areas due to the intense concentration of people, infrastructure and resources that may be affected by a damaging earthquake. As a result, disaster management plans that are prepared without carrying out rigorous risk assessment and scenario development are unable to take advantage of this information for optimal prioritization of resources and monitoring long-term reduction of risk.

1.3 Seismic Risk

The assessment of seismic risk involves the estimation of consequences of an earthquake in the chosen area in terms of the expected damage and loss from a given hazard to given elements at risk. For The risk assessment involves evaluation of seismic hazard, vulnerability of structures, exposure and finally loss estimation. Thus, the total risk can be expressed simply in the following conceptual form.

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability} \times \text{Exposure} \tag{1}$$

Seismic hazard quantifies the ground motions generated due to an earthquake. Any local effect such as due to soil properties is incorporated in hazard assessment. The seismic vulnerability quantifies the propensity of types of buildings to be damaged due to specified ground motions. When carrying out risk assessment of large areas, where the built environment information may be available only at low resolution, vulnerability of the buildings implied in macro-seismic intensity scales is most commonly used. The method utilizes damage probability matrices that estimate the level of damage corresponding to ground motion intensity as a conditional probability factor. Different buildings vary in their degree of vulnerability to earthquake ground motions as a function of geometrical or qualitative characteristics (such as height, plan dimensions and elevation configurations, age etc.), and structural characteristics (such as material of construction, mass, stiffness, quality of construction, strength, intrinsic ductility, state of stress, seismic displacements, non-linear behaviour parameters and other structural information). Hence there is a need to classify the buildings by type and use. The vulnerability of buildings can be encapsulated by identifying the building type from a standard building typology catalogue.

1.4 Building Typology for Seismic Vulnerability Assessment

The earthquake resistance of buildings greatly influences seismic losses. The overwhelming majority of deaths and injuries in earthquakes occur because of the disintegration and collapse of buildings, and much of the economic loss and social disruption caused by earthquakes is also attributable to the failure of buildings and other human-made structures.

Studies of earthquake damage show that some types of construction tend to be more vulnerable than others. The form of construction of the main vertical load-bearing elements is one of the main determinants of vulnerability of a building. For instance, a building with unreinforced masonry walls can be expected to be much more vulnerable than a timber frame building. Thus, preparation of a building typology catalogue and using the catalogue for seismic vulnerability assessment is necessary (Coburn and Spence, 2002).

A standard building typology catalogue has not been prepared in the country that considers the resistance of buildings to earthquake ground motions as the primary criteria. Preliminary efforts in classifying construction typology for housing in India highlight the diversity in materials and technologies used in construction within the country (EERI-IAEE, 2002).

From the understanding of the problem and the observations regarding wide variation in behaviour of buildings to earthquake ground motions, it is important that a Building Typology Catalogue of India be prepared from seismic vulnerability considerations. The building types given in the catalogue should further be analysed to determine the vulnerability of the each building type. This should also consider the modifications to the vulnerability due to geometric and/or structural modifiers. The outcome of this effort can then provide invaluable information for carrying out earthquake damage scenario analysis, and thereby help to quantify the seismic risk in different parts of the country.

The necessity of preparing a building typology catalogue in the country and determination of seismic vulnerability of different building types has been recognised by experts. In the absence of a building typology catalogue, the Buildings Materials Technologies Promotion Council (BMTPC) has used housing census data for preparing the Vulnerability Atlas of India. The Atlas has provided potential damageability of different buildings on the basis of their material of construction. A more detailed assessment has not been feasible in any country-wide study in the absence of the building typology catalogue, the seismic vulnerability functions and more detailed information on built environment.

Some damage scenario studies have considered the seismic vulnerability of some building types in pilot areas (Arya, 2008, Sinha and Adarsh, 1999, Gulati, 2006, Prasad et al., 2009). These studies have considered sample areas and have provided earthquake damage scenario based on the available information and limited data collection. The structural characteristics of buildings in these studies were not collected to develop the building typology catalogue and thus not directly useful for this work. Apart from modern constructions in urban and semi-urban areas, vernacular architecture and non-engineered, traditional construction techniques are widespread, not only in rural and semi-urban areas, but they also constitute a majority of the dwellings in urban historical nuclei. Hence there is a need to quantify the seismic resistance of such traditional constructions.

1.5 Scope of the Technical Document

The present document focuses on preparing a standard building typology catalogue for seismic vulnerability assessment in India. It discusses building typologies for seismic risk assessment proposed in published literature and in other countries. Thus, it gives an insight into various parameters used for building classification that are considered useful for this purpose.

It also describes proposed building typology catalogue based on various parameters. The methodology for preparing a standard building catalogue has also been developed.

Chapter 2 Building Typologies for Seismic Vulnerability Assessment

India is one of the most seismically active countries of the world, and past earthquakes have exposed the high seismic vulnerability of its housing stock, resulting in huge life and economic losses. In seismic risk assessment, estimation of earthquake hazard, structural vulnerability and exposure of building stock are the three equally important components, out of which, the development of inventory databases is the most difficult aspect of damage prediction (ATC-13, 1985). For earthquake scenarios for larger areas or for a whole town, it is hardly possible to evaluate each individual building for seismic vulnerability. It is therefore desirable to classify the buildings by means of a few characteristic parameters based on the results of the evaluation of the buildings in the target area.

The definition of a classification system for the characterization of the exposed building stock and the description of its damage is an essential step in a risk analysis in order to ensure a uniform interpretation of data and results.

For general building stock the following parameters affect the damage and loss characteristics:

i) Structural (system, height, and building practices etc.) and
ii) Non-structural elements (occupational and functional components, or OFCs) and its Occupancy (residential, commercial, industrial, lifeline etc.).

This chapter gives a brief review of the various building typologies which are identified in various parts of the World for seismic vulnerability considerations.

2.1 Building Typology Classifications Systems

2.1.1 MSK 64 Scale

The MSK (Medvedev-Sponheuer-Karnik) scale was approved in 1964 by UNESCO as the international standard in seismology. Evaluation criteria of the intensity of ground vibrations are the values of both acceleration and speed, describing the vibration effect on the surface and people's reactions assigned to each level of intensity. The description of possible results (damage to buildings) assigned to three designated groups of buildings with the amount of this damage is a complement to these criteria. These three building types are described in Table 2.1.

This is a very simplistic classification system and does not recognize the possibly large variation in seismic vulnerability of different buildings using same construction materials. However, during post-earthquake damage survey, the level of damage to buildings classified using this method provides a useful input for damage intensity estimation.

Table 2.1: MSK 64 Scale Building Typology (IS 1893-2002)

Type	Construction Type
A	Building in field-stone, rural structures, unburnt-brick houses, clay houses
B	Ordinary brick buildings, buildings of large block and prefabricated type, half timbered structures, buildings in natural hewn stone
C	Reinforced buildings, well built wooden structures

This scale is not intended for vulnerability assessment of buildings, but only for estimation of earthquake intensity where structural damage is an important parameter.

2.1.2 ATC-13 Classification

The Applied Technology Council of USA proposed a building classification for seismic vulnerability assessment in 1985. This report has primarily considered buildings in California, USA. The building classification considered the influence of several parameters and was not just based on the material of construction. The parameters used to classify buildings included the following:

i) Construction material
ii) Height of the building
iii) Structural framing system
iv) Design and construction quality

Table 2.2: ATC-13 Building Classification (ATC-13, 1985)

Construction Material	Load Resisting System	Height of Building
Reinforced Concrete	With Moment Resisting Frame Ductile Concrete Frame	Low Rise Medium Rise High Rise
	With Moment Resisting Frame Non-Ductile Concrete Frame	Low Rise Medium Rise High Rise
	Without Moment Resisting Frame	Low Rise Medium Rise High Rise
Precast Concrete	Other than Tilt-up	Low Rise Medium Rise High Rise
Reinforced Masonry Shear Wall	With Moment Resisting Frame	Low Rise Medium Rise High Rise
	Without Moment Resisting Frame	Low Rise Medium Rise

Construction Material	Load Resisting System	Height of Building
		High Rise
Unreinforced Masonry	With Bearing wall	Low Rise Medium Rise
	With Load Bearing Frame	Low Rise Medium Rise High Rise
Steel	With Moment Resisting Frame Perimeter Frame	Low Rise Medium Rise High Rise
	With Moment Resisting Distributed Frame	Low Rise Medium Rise High Rise
	Braced Steel Frame	Low Rise Medium Rise High Rise
Wood Frame	---	Low Rise
Light Metal	---	Low Rise

ATC-13 thus provided 34 different building classes based on construction material, load resisting system and height of the building. The building typology suggested in ATC-13 is useful for classification of structural vulnerability of buildings.

2.1.3 EMS Scale

European Macroseismic Scale (EMS) scale was developed based on an earlier modification of the MSK-64 scale which was widely used in Europe for nearly 30 years. The first modification took place in 1981, the improved EMS scale in 1992 was recommended for use by the General Association ESC-1992 for the trial period. The next modifications of the EMS scale were made with the application of computer methods for estimating macroseismic data.

The modifications introduced improved this scale, but did not change its basic assumptions. In 1998, the European Seismological Commission (ESC) approved the most current version of the EMS scale. The building typologies defined in EMS-98 scale are presented in Table 2.3.

It can be seen that buildings are classified mainly based on their material of construction, which is very similar to the basic classification used in MSK intensity classification. This classification is adopted by various European countries for seismic vulnerability assessment. For each of the building type defined, possible vulnerability range is also specified for European construction types.

Table 2.3: EMS Scale Building Typology (Gruenthal, 1998)

Construction Type	Construction Subtype
Masonry	Rubble Stone, Fieldstone
	Adobe (Earth Brick)
	Simple Stone
	Massive Stone
	Unreinforced with manufactured stone units
	Unreinforced, with RC floors reinforced or confined
Reinforced Concrete	Frame without Earthquake Resistant Design (ERD)
	Frame with Moderate Level of ERD
	Frame with High Level of ERD
	Walls without ERD
	Walls with Moderate Level of ERD
	Walls with High Level of ERD
Steel	Steel Structures
Timber	Timber Structures

The EMS building typology catalogue is intended primarily for estimation of damage intensity following an earthquake. However, the building classification system also provides sufficient information to assess the vulnerability range for the buildings evaluated using this method.

2.1.4 FEMA 154/FEMA 310/HAZUS

A building classification type was proposed by FEMA in the USAfor rapid visual survey of structural vulnerability. For rapid visual screening of buildings in United States, FEMA (Federal Emergency Management Agency) 154 classifies buildings on the basis of structural material and lateral load resisting system. The model building types defined in FEMA 154-2002 are illustrated in Table 2.4.

Table 2.4: Model Building Types in FEMA 154-2002 (FEMA 154, 2002)

ID	Building Typologies
C: Reinforced Concrete	
C1	Moment Resisting Frame
C2	With Shea Walls
C3	With URM Infill Walls
PC1	Precast Concrete - Tilt-Up Buildings
PC2	Precast Concrete Frame
RM: Reinforced Masonry	

ID	Building Typologies
RM1	Reinforced Masonry with Flexible Diaphragms
RM2	Reinforced Masonry with Rigid Diaphragms
URM: Unreinforced Masonry	
URM	Unreinforced Masonry
S: Steel Typologies	
S1	Steel Moment Resisting Frame
S2	Braced Steel Frame
S3	Light Frame
S4	With RC Shear Walls
S5	With URM Infill Walls
W: Timber Typologies	
W	Light wood-frame

From Table 2.4, it is seen that the building classification has become more detailed over the period of time. This classification has given a label for each building type. Building types are defined based on construction material and load resisting system. HAZUS further extends this classification considering height of the building as a building classification parameter. Similar classification is also used in FEMA 310.

This building typology system is useful for classification of structural vulnerability of buildings. FEMA-154 also recommends collection of additional information regarding structural irregularities, number of occupants, etc. which are useful information for assessing the impact of damage to the building due to earthquake.

2.1.5 Coburn and Spence (2002)

Coburn and Spence (2002) provide a classification of the construction types found in many seismic areas of the world (Table 2.5), and a similar detailed categorization of load-bearing systems is presented in the EERIWorld Housing Encyclopaedia (Table 2.6). This system of classification is an extension of the basic system used for MSK-64 classification. In addition to more detailed information on construction materials, this classification system also considers the structural system and salient details of construction techniques that significantly influence the seismic vulnerability. The method can therefore be considered to be a sub-classification of simple building types used in MSK-64 classification so that the information can be used for seismic vulnerability assessment.

The vulnerability of these construction types, on average, can be expected to decrease from the top to the bottom of both classification systems. For instance, non-engineered structures are more vulnerable than engineered ones, and rubble stone and earthen structures are more vulnerable than timber ones, within the category of non-engineered structures.

Table 2.5: Coburn and Spence Building Types (Coburn and Spence, 2002)

	Construction Type Classification	Main Structural Classification	Building Type

	Construction Type Classification	Main Structural Classification	Building Type
Non-Engineered Buildings	Masonry Type A Weak masonry	AR Rubble stone	AR1 Rubble stone masonry in mud or lime mortar
		AE Earthen	AE1 Rammed earth construction, earth cob, pise or solid soil
			AE2 Composite earth with timber or fibre, wattle and daub, earth and bamboo
		AA Adobe (earth brick)	AA1 Adobe sun-dried earth brick in mud mortar
		BB Unreinforced brick	BB1 Unreinforced fired brick masonry in cement mortar
			BB2 Brick masonry with horizontal reinforcement
		BC Concrete block	BC1 Concrete block
		BD Dressed stone masonry	BD1 Stone masonry, squared and cut, dimensioned stone, monumental
		CC Reinforced concrete (RC) frame cast in situ	CC1 Reinforced concrete frame, in situ
		CT Timber frame	CT1 Timber frame with heavy infill masonry
			CT2 Timber frame with timber cladding, lightweight structure
Engineered Buildings	Building Type D Engineered Structures	DB Reinforced unit masonry	DB1 Reinforced brick masonry
		DC In situ RC frame	DC1 In situ RC frame with non-structural cladding
			DC2 In situ RC frame with infill masonry
			DC3 In situ RC frame with shear wall
		DP Precast RC structure	DP1 Precast RC frame with infill masonry
			DP2 Precast RC frame with concrete shear walls
			DP3 Precast large-panel structure
		DH Hybrid or composite steel/RC	DH1 Composite steel frame with

	Construction Type Classification	Main Structural Classification	Building Type
		structures	in situ RC casting
		DS Steel frame structures	DS1 Light steel frame (portal frame, steel truss, low rise)
			DS2 Steel frame, moment resistant
			DS3 Steel frame with infill masonry
			DS4 Steel frame, braced
			DS5 Steel frame with RC shear wall or core

The building vulnerability classification system proposed by Coburn and Spence was one of the early proposals to capture structural information for seismic risk assessment purposes.

2.1.6 World Housing Encyclopaedia (WHE)

The Earthquake Engineering Research Institute (EERI) has a project currently underway to build an interactive web-based encyclopaedia of housing construction types in seismically active areas of the world. This project is called the World Housing Encyclopaedia (WHE). This endeavour has linked over 180 volunteer engineers and architects from many diverse countries and regions.

The purpose of the encyclopaedia is to develop a comprehensive global categorisation of characteristic housing construction types across the world. A housing type being practiced anywhere in the world is presented as a Housing Report using a standard information format. So, every report includes all relevant aspects of housing construction, such as socio-economic issues, architectural features, structural system, seismic deficiencies and earthquake-resistant features, performance in past earthquakes, available strengthening technologies, building materials used, construction process employed, and insurance information for the given country. In addition to the text and numerical information, several illustrations (photos, drawings, sketches) are also included in the report. A report for a particular housing type can contain over 20 pages of text and figures. All reports comprise a searchable database of global housing construction. The building classification used by World Housing Encyclopaedia is given in Table 2.6.

Table 2.6: WHE Building Types

Material	Lateral Load Resisting System	Sub- Types
Masonry	Stone Masonry Walls	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)
		Massive stone masonry (in lime/cement mortar)
	Earthen/Mud/	Mud walls

Material	Lateral Load Resisting System	Sub- Types
	Adobe/Rammed Earthen Walls	Mud walls with horizontal wood elements
		Adobe block walls
		Rammed earth/Pise construction
	Burnt clay brick/block masonry walls	Unreinforced brick masonry in mud mortar
		Unreinforced brick masonry in mud mortar with vertical posts
		Unreinforced brick masonry in lime mortar
		Unreinforced brick masonry in cement mortar with reinforced concrete floor/roof slabs
		Unreinforced brick masonry in cement mortar with lintel bands (various floor/roof systems)
		Confined brick/block masonry with concrete posts/tie columns and beams
	Concrete block masonry	Unreinforced, in lime/cement mortar (various floor/roof systems)
		Reinforced, in cement mortar (various floor/roof systems)
Structural Concrete	Moment Resisting Frame	Designed for gravity loads only (predating seismic codes i.e. no seismic features)
		Designed with seismic features (various ages)
		Frame with unreinforced masonry infill walls
		Flat slab structure
		Precast frame structure
		Frame with concrete shear walls (dual system)
	Shear Wall Structure	Walls cast in-situ
		Precast wall panel structure
Steel (ST)	Moment Resisting Frame	With brick masonry partitions
		With cast in-situ concrete walls
		With lightweight partitions
	Braced Frame	With various floor/roof systems
	Light Metal Frame	Single storey LM frame structure
Wooden Structures (WO)	Load Bearing Timber Frame	Thatch roof
		Post and beam frame
		Walls with bamboo/reed mesh and post (Wattle

Material	Lateral Load Resisting System	Sub- Types
		and Daub)
		Frame with (stone/brick) masonry infill
		Frame with plywood/gypsum board sheathing
		Frame with stud walls

(Source: http://www.world-housing.net)

The building typologies proposed by WHE are very detailed and consider construction material, lateral load resisting system and structural characteristics of the system. This classification system is thus also useful for seismic risk assessment. The vulnerability class for each building type is also specified.

2.1.7 RISK-UE

A comprehensive building typology classification for Europe, that incorporated the characteristic features of the European building taxonomy, was developed in the European Commission funded RISK-UE project (RISK-UE, 2001-2004) entitled "An Advanced Approach to Earthquake Risk Scenarios with Application to Different European Towns". The building taxonomy developed in RISK-UE is given in Table 2.7.

Table 2.7: RISK-UE Building Typology (Mourox, 2004)

Taxonomy	Description	Sub-classification
M1	Stone Masonry Bearing Walls made of	Rubble stone, fieldstone (M1.1)
		Simple stone (M1.2)
		Massive stone (M1.3)
M2	Adobe	
M3	Unreinforced Masonry Bearing Walls with	Masonry with wooden slabs (M3.1)
		Masonry vaults (M3.2)
		Composite steel and masonry slabs (M3.3)
		Reinforced concrete slabs (M3.4)
M4	Reinforced or confined masonry walls	
M5	Overall strengthened	
RC 1	Concrete moment frame	
RC 2	Concrete shear walls	
RC 3	Concrete frames with unreinforced masonry infill walls	Regularly infilled walls (RC 3.1)
		Irregularly infilled walls (RC 3.2)

Taxonomy	Description	Sub-classification
RC 4	RC dual systems (RC frame and wall)	
RC 5	Precast concrete tilt-up walls	
RC 6	Precast C. Frames, C. Shear walls	
S1	Steel moment frame	
S2	Steel braced frame	
S3	Steel frame + unreinforced infill walls	
S4	Steel frame + cast-in-place shear walls	
S5	Steel and RC composite system	
W	Wood structures	

This classification system does not include several non-engineered building types presented earlier, due to their low proportion out of the total building stock in Europe. In all, 23 building types have been proposed.

2.1.8 PAGER Classification

United States Geological Survey is currently carrying out a program called PAGER (Prompt Assessment of Global Earthquakes for Response) that includes a global building inventory database. The inventory development in PAGER consists of estimates of the fractions of building types observed in each country, their functional use, and average day and night occupancy. Various data sources exist that provide building-specific information at a local or regional level with varying degrees of confidence; however, few data sources have been found to be relevant, consistent, and useful to our needs on a global scale. The inventory development methodology presented by PAGER not only compiles data from various sources but also allows rating and selecting the best source based on its vintage and quality (Jaiswal and Wald, 2008).The detailed building classification is given in Table 2.8.

Table 2.8: PAGER Building Inventory (Jaiswal and Wald, 2008)

Label	Description (according to construction/structure type)	Average number of stories
W	WOOD	1-3
W1	Wood Frame, Wood Stud, Wood, Stucco, or Brick Veneer	1-2
W2	Wood Frame, Heavy Members, Diagonals or Bamboo Lattice, Mud Infill	All
W3	Wood Frame, Prefabricated Steel Stud Panels, Wood or Stucco Exterior Walls	2-3
W4	Log building	1-2
S	STEEL	All
S1	Steel Moment Frame	All

S1L	Low-Rise	1-3
S1M	Mid-Rise	4-7
S1H	High-Rise	8+
S2	Steel Braced Frame	All
S2L	Low-Rise	1-3
S2M	Mid-Rise	4-7
S2H	High-Rise	8+
S3	Steel Light Frame	All
S4	Steel Frame with Cast-in-Place Concrete Shear Walls	All
S4L	Low-Rise	1-3
S4M	Mid-Rise	4-7
S4H	High-Rise	8+
S5	Steel Frame with Un-reinforced Masonry Infill Walls	All
S5L	Low-Rise	1-3
S5M	Mid-Rise	4-7
S5H	High-Rise	8+
C	REINFORCED CONCRETE	All
C1	Ductile Reinforced Concrete Moment Frame	All
C1L	Low-Rise	1-3
C1M	Mid-Rise	4-7
C1H	High-Rise	8+
C2	Reinforced Concrete Shear Walls	All
C2L	Low-Rise	1-3
C2M	Mid-Rise	4-7
C2H	High-Rise	8+
C3	Non ductile Reinforced Concrete Frame with Masonry Infill Walls	All
C3L	Low-Rise	1-3
C3M	Mid-Rise	4-7
C3H	High-Rise	8+
C4	Non ductile Reinforced Concrete Frame without Masonry Infill Walls	All

C4L	Low-Rise	1-3
C4M	Mid-Rise	4-7
C4H	High-Rise	8+
C5	Steel Reinforced Concrete (Steel Members Encased in Reinforced Concrete)	All
C5L	Low-Rise	1-3
C5M	Mid-Rise	4-7
C5H	High-Rise	8+
PC1	Precast Concrete Tilt-Up Walls	All
PC2	Precast Concrete Frames with Concrete Shear Walls	All
PC2L	Low-Rise	1-3
PC2M	Mid-Rise	4-7
PC2H	High-Rise	8+
RM	REINFORCED MASONRY	All
RM1	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms	All
RM1L	Low-Rise	1-3
RM1M	Mid-Rise (4+ stories)	4-7
RM2	Reinforced Masonry Bearing Walls with Concrete Diaphragms	All
RM2L	Low-Rise	1-3
RM2M	Mid-Rise	4-7
RM2H	High-Rise	8+
MH	Mobile Homes	All
M	MUD WALLS	1
M1	Mud Walls without Horizontal Wood Elements	1-2
M2	Mud Walls with Horizontal Wood Elements	1-3
A	ADOBE BLOCK (UNBAKED DRIED MUD BLOCK) WALLS	1-2
A1	Adobe Block, Mud Mortar, Wood Roof and Floors	1-2
A2	Same as A1, Bamboo, Straw, and Thatch Roof	1-2
A3	Same as A1, Cement-Sand Mortar	1-3

A4	Same as A1, Reinforced Concrete Bond Beam, Cane and Mud Roof	1-3
A5	Same as A1, with Bamboo or Rope Reinforcement	1-2
RE	RAMMED EARTH/PNEUMATICALLY IMPACTED STABILIZED EARTH	1-2
RS	RUBBLE STONE (FIELD STONE) MASONRY	All
RS1	Local Field Stones Dry Stacked (No Mortar). Timber Floors. Timber, Earth, or Metal Roof.	1-2
RS2	Same as RS1 with Mud Mortar.	1-2
RS3	Same as RS1 with Lime Mortar.	1-3
RS4	Same as RS1 with Cement Mortar, Vaulted Brick Roof and Floors	1-3
RS5	Same as RS1 with Cement Mortar and Reinforced Concrete Bond Beam.	1-3
DS	RECTANGULAR CUT STONE MASONRY BLOCK	All
DS1	Rectangular Cut Stone Masonry Block with Mud Mortar, Timber Roof and Floors	1-2
DS2	Same as DS1 with Lime Mortar	1-3
DS3	Same as DS1 with Cement Mortar	1-3
DS4	Same as DS2 with Reinforced Concrete Floors and Roof	1-3
UFB	UNREINFORCED FIRED BRICK MASONRY	All
UFB1	Unreinforced Brick Masonry in Mud Mortar without Timber Posts	1-2
UFB2	Unreinforced Brick Masonry in Mud Mortar with Timber Posts	1-2
UFB3	Unreinforced Fired Brick Masonry, Cement Mortar, Timber Flooring, Timber or Steel Beams and Columns, Tie Courses (Bricks Aligned Perpendicular to the Plane of the Wall)	1-3
UFB4	Same as UFB3, but with Reinforced Concrete Floor and Roof Slabs	1-3
UCB	UNREINFORCED CONCRETE BLOCK MASONRY, LIME/CEMENT MORTAR	All

MS	MASSIVE STONE MASONRY IN LIME/CEMENT MORTAR	All
TU	PRECAST CONCRETE TILT-UP WALLS (same as HAZUS Type PC1 in Developing and Undeveloped Countries)	All
INF	INFORMAL CONSTRUCTIONS (parts of Slums/Squatters) Constructions Made of Wood/Plastic Sheets/Galvanized Iron sheets/Light Metal or Composite etc., not Confirming to Engineering Standards.	All
UNK	Unknown Category (Not specified)	All

As can be seen in the above table, PAGER classification system has defined comprehensive building typologies considering construction material, load resisting system, number of stories and other structural characteristics. These structure types are used to classify buildings world-wide, and to prepare global building inventory. Prevalent construction types in various countries are categorized as PAGER structural types in their global building inventory.

2.1.9 Global Earthquake Model (GEM) Taxonomy

The Global Earthquake Model (GEM), as one of their global component, is developing a global taxonomy of construction types around the world. The work is in its initial state of development, and is expected to be completed by 2012. The key concept for the proposed GEM taxonomy is that of a faceted taxonomy, as opposed to more traditional (and as described above) hierarchical taxonomies.

GEM taxonomy is organized as a series of expandable tables, which contain information about facets. Each facet describes a specific characteristic of a building. There are two types of facets:

- Main facets describe most general building characteristics, and
- Secondary facets describe main facets in more detail.

Each main facet can have one or more secondary facets. All main and secondary facets included in the GEM taxonomy are listed in Table 2.9.

Table 2.9: Main and Secondary Facets Considered for Building Classification (Brzev, 2011)

ID	Main Facet	Secondary Facets
HE	Height	Height above grade
		Number of stories
		Height category
		First story height
		Tall story height

ID	Main Facet	Secondary Facets
WE	Exterior Walls	
RO	Roof	Roof shape
		Roof material
PL	Plan	Footprint
		Dimensions
		Area
HZ	Building Hazards	Falling
		Pounding
		Fire resistance – roof
		Fire resistance – building
AG	Construction Date	Construction completed
		Design completed
CN	Building condition	
FL	Floor Level	
OC	Occupancy	Occupancy – general
		Occupancy – subclass level 1
		Occupancy – subclass level 2
SD	Structure: Direction	
SV	Lateral Load Resisting System	Principal lateral structural element
		Connections/reinforcement/detailing
MA	Material	Material type
		Material properties
SD	Ductility	
IR	Structural Irregularity	Horizontal irregularity
		Vertical irregularity
SH	Floors and Roof	Type
		Diaphragm
		Diaphragm structural system
FO	Foundations and Site Soil Conditions	Foundation system
		Number of basements
		Soil conditions
NS	Non-structural Components	
BC	Building Codes	Code compliance

ID	Main Facet	Secondary Facets
		Code information
RE	Seismic Retrofit	

Each main facet has been given a two letter alphabetical label. Further each main facet has number of secondary facets which explain the various aspect of the main facet.

Based on material type, lateral load resisting system and structural element, following building typologies are defined in GEM-Taxonomy.

Table 2.10: Building Typologies defined in proposed GEM-Taxonomy (Brzev, 2011)

Material Type	Lateral Load Resisting System	Principal Lateral Structural Element	Building Typology
Reinforced concrete	Wall	Precast panel	Precast concrete wall building (or tilt-up building)
		Solid wall	RC shear wall system
		Coupled wall	RC shear wall system
	Rigid frame	Unreinforced masonry infill	RC frame with masonry infills
		Reinforced masonry infill	RC frame with masonry infills
	Flat slab/flat plate		
	Dual system	Unreinforced masonry infill	Frame-wall system
		Reinforced masonry infill	
	Braced frame	Reinforced concrete bracing	Braced RC frame system (found in Romania)
Steel	Rigid frame	Unreinforced masonry infill	
		Reinforced masonry infill	
	Wall	Steel plate shear wall	Steel plate shear wall system found in buildings in US and Canada
	Braced frame	Steel bracing,	

Material Type	Lateral Load Resisting System	Principal Lateral Structural Element	Building Typology
		triangulated	
		Steel bracing, tension-only	
		Steel bracing, eccentric	
	Wall	Steel studs lined with sheet material	Light steel frame
Masonry	Wall	Unreinforced masonry bearing wall	Bearing wall structure
		Reinforced masonry bearing wall	Bearing wall structure
		Confined masonry	Confined masonry building
Earthen	Wall	Adobe masonry bearing wall	
		Pise (Rammed Earth)	
		Cob (Built up earth)	

It can be seen that the building typologies defined in Table 2.10 are based on some of the main facets defined in Table 2.9. Though Table 2.10 describes the building typologies very precisely, wooden or timber structures are not taken into account while doing categorisation of buildings.

2.2 Building Typology in Various Countries

Several country-specific initiatives have been taken from time to time to develop building categorization for a particular country or a region. This section provides the building categorization system from seismic vulnerability considerations proposed in various countries.

2.2.1 Armenia

The 1988 earthquake in Armenia was the most serious seismic disaster since the 1976 earthquake in Tangshan, China. At least 25,000 people lost their lives in a tremor of moderate magnitude. The structural characteristics of all the residential building types existing in the affected area are presented in terms of their seismic vulnerability as shown in Table 2.11.

Table 2.11: Residential Building Typologies in Armenia (Pomonis, 1990)

Sr. No.	Structural System	Vertical Structure	Horizontal Structure
1.	Load Bearing Masonry	Midis	Timber Floors
		Tuff Unreinforced	Timber Floors/ Precast

Sr. No.	Structural System	Vertical Structure	Horizontal Structure
			RC Planks
2.	Framed Structure	Precast RC Frame	Cast in-situ RC Slab
3.	Panel System	Precast RC Panel	Precast RC Planks
4.	Mixed Structure	Tuff Reinforced	Precast RC Planks
		Lift-Slab (high-rise apartment buildings)	Precast RC Planks

It is noticeable that the structures for carrying the lateral loads are either masonry or reinforced concrete (steel frames are seldom used, and only in industrial buildings). Also noteworthy is the almost complete lack of monolithic RC frames or slabs that nowadays are only used for important buildings (hospitals, government offices etc.).

2.2.2 Australia

Information about nationwide building inventory in Australia is quite limited. The information about construction characteristics was not available from any of the UN databases even in their recent compilations (Jaiswal and Wald, 2008). However, Building inventory is given in Geoscience data based upon the type of wall in residential buildings. The classification based on Geoscience building inventory is given in Table 2.12.

Table 2.12: Classification of Building Types in Australia

Sr. No.	Construction by Type of Wall	ID
1	Unreinforced Masonry(Double Brick or English bond)	URM
2	Timber Frame (Brick Veneer)	W1
3	Reinforced Concrete Frame with Masonry infill (above 2 storeys)	-NA-

(Source: http://www.ga.gov.au/image_cache/GA4197.pdf)

This categorization divides buildings into 3 categories depending upon whether the building is made of masonry, timber or reinforced concrete. This categorization is very similar to that used in MSK-64 intensity scale and is not suitable for seismic vulnerability assessment.

2.2.3 Canada

For seismic vulnerability assessment of building in Vancouver City, Canada, Onur et al. (2004) have proposed the following characteristics for building classification.

i) Material of Construction
ii) Lateral Load Resisting System
iii) Structural Characteristics

Table 2.13 presents the various building types defined for seismic vulnerability assessment of buildings in Vancouver City, Canada.

Table 2.13: Building Typologies in Vancouver, Canada (Onur et al., 2004)

Sr. No.	Material	Building Class Description	Code
1	Wood	Wood light frame residential (single family)	WLFR
2		Wood light frame low rise commercial/institutional	WLFCI
3		Wood light frame low rise (up to 4 stories) residential	WLFLR
4		Wood post and beam	WPB
5	Steel	Light metal frame	LMF
6		Steel moment frame low rise (up to 3 stories)	SMFLR
7		Steel moment frame mid rise (4 to 7 stories)	SMFMR
8		Steel moment frame high rise (8 stories and higher)	SMFHR
9		Steel braced frame low rise	SBFLR
10		Steel braced frame mid rise	SBFMR
11		Steel braced frame high rise	SBFHR
12		Steel frame with concrete walls low rise	SFCWLR
13		Steel frame with concrete walls mid rise	SFCWMR
14		Steel frame with concrete walls high rise	SFCWHR
15		Steel frame with concrete infill walls	SFCIW

Sr. No.	Material	Building Class Description	Code
16		Steel frame with masonry infill walls	SFMIW
17	Concrete	Concrete frame with concrete walls low rise	CFCWLR
18		Concrete frame with concrete walls mid rise	CFCWMR
19		Concrete frame with concrete walls high rise	CFCWHR
20		Concrete moment frame low rise	CMFLR
21		Concrete frame with concrete walls mid rise	CMFMR
22		Concrete frame with concrete walls high rise	CMFHR
23		Concrete frame with infill walls	CFIW
24	Masonry	Reinforced masonry shear wall low rise	RMLR
25		Reinforced masonry shear wall mid rise	RMMR
26		Unreinforced masonry bearing wall low rise	URMLR
27		Unreinforced masonry bearing wall mid rise	URMMR
28	Tilt up	Tilt up	TU
29	Precast	Precast concrete low rise	PCLR
30		Precast concrete mid rise	PCMR
31	Mobile	Mobile homes	MH

There are 31 building typologies defined in this study. Each building typology is given a unique code. This code is given as per the various parameters considered for the classification. These building typologies are used for seismic vulnerability assessment of various cities in Canada such as Vancouver and Quebec City.

2.2.4 Greece

The extent and quality of building inventory varies substantially within the various databases compiled in Greece. The building inventories are compiled as a part of earthquake damage data, collected post-event; for the purposes of loss/risk assessment projects and for the national building census conducted every 10 years. Building typologies from the building inventories are presented in Table 2.14.

Table 2.14: Building Typology in Greece (Kappos and Panagopoulos, 2011)

Material	Sub-type	Structural System	Number of Storeys	Presence of infills/pilotis
RC	Old (1959 code)	Moment Frame	1. 1-3 storeys 2. 4-7 storeys 3. > 8 storeys	1. Bare 2. Regularly infilled 3. Pilotis
		Dual System		
	Mid-Period Building (1984 code)	Moment Frame		
		Dual System		
	Modern Building (Post 2000)	Moment Frame		
		Dual System		
Masonry	Unreinforced Masonry	stone masonry	1. 1-2 storeys 2. > 3 storeys	—

2.2.5 Iran

A brief statistical assessment of the seismic vulnerability of buildings in Iran was carried out by Mostafaei and Kabeyasawa. Based on the results, Iran was concluded to be one of the most vulnerable countries in the world to earthquake. A post-earthquake building damage survey was performed in Bam city, Iran, after the catastrophic earthquake of December 26, 2003. Subsequently, studies were carried out on the building damage data collected. Based on the results, adobe and masonry buildings, which are the major types of structure in Bam city, were found to have suffered the highest level of damage. Reinforced concrete buildings with infilled masonry walls and masonry buildings with reinforced concrete ties, however, were structures with very low levels of damage. Based on the statistical studies, buildings in Bam city, Iran were classified into following building categories as shown in Table 2.15.

Table 2.15: Building Typologies in Iran (Mostafaei and Kabeyasawa, 2004)

Sr. No.	Structural Types	Building Category
1	Adobe Structures with Clay and Straw	Ad

Sr. No.	Structural Types	Building Category
2	Masonry with Cement Mortar	M
3	Masonry with Mud/Lime Mortar	M-Ad
4	Masonry with reinforced concrete ties	M-C
5	Masonry with steel frame ties	M-S
6	Special Steel Frame Masonry	M-S-F
7	Steel frame buildings with masonry brick walls	M-S
8	Steel frame with bracing	S-B
9	Steel frame with moment resisting connections	S-F
10	Reinforced Concrete Frame	RC

2.2.6 Italy

Seismic vulnerability assessment of dwelling buildings was carried out in Basilicata region in Southern part of Italy by Masi. The typological data for various building types were collected for Potenza town and Val d' Agriarea which comprises 18 small villages with 18, 000 buildings. The buildings were surveyed using vulnerability survey forms. The relevant portion of the survey form used for classification of buildings is shown below in Table 2.16 and 2.17.

Table 2.16: Masonry building typologies in Italy (Masi, 2011)

Vertical Structures / Horizontal Structures	Unknown	Masonry: Irregular lay-out and bad quality (stones, pebble, etc.): Without ties or tie beams	Masonry: Irregular lay-out and bad quality (stones, pebble, etc.): With ties or tie beams	Masonry: Regular lay-out and good quality (Hewn stones, bricks, etc.): Without ties or tie beams	Masonry: Regular lay-out and good quality (Hewn stones, bricks, etc.): With ties or tie beams	Isolated Columns	Mixed Structure	Strengthened
Unknown								
Vaults without ties								
Vaults with ties								
Flexible floors								
Semirigid floors								
Rigid floors								

Table 2.17: RC and Steel building typologies in Italy (Masi, 2011)

Sr. No.	Structure Type	Load Resisting System	Irregularity
1.	RC structure	RC frame structure	Irregularity in plan and elevation
			Irregularity in Cladding distribution
		RC Shear wall structure	Irregularity in plan and elevation
			Irregularity in Cladding distribution
2.	Steel structure	Steel frame structure	Irregularity in plan and elevation
			Irregularity in Cladding distribution

Another system of building categorization is proposed. The buildings were categorized into various classes using following system of classification shown in Table 2.18. The review of this study reveals that moment resisting frames are the most widespread structural type.

Table 2.18: Building typologies in Italy (Masi, 2011)

Material	Structural System
RC	Structural walls or frames with effective infills
	Frames with rigid beams and without infills
	Frames with flexible beams and without infills
	Frames with rigid beams along the perimeter and internal flexible beams, without effective infills
	Dual system: frames with rigid beams plus cores
	Structural walls
Masonry	Stone Masonry House
	Historic Brick Masonry House
	Brick Masonry farm house with dead door
	Casa Torre Construction: multistory tower masonry with stone pillars and wood or arched beams
	multistory tower masonry with stone pillars and wood or arched beams
	Unreinforced stone wall rural housing (lower and middle income)

2.2.7 Japan

Japanese residential building inventory database has been compiled at the city/ward level by using following parameters:

i) Construction Material
ii) Occupancy
iii) Height
iv) Year of Construction

The detailed building classification in Japan is given in Table 2.19.

Table 2.19: Residential housing type data for Japan (Jaiswal and Wald, 2008)

Material Types	Sub-Types
Reinforced Concrete	Moment resisting frame design with seismic features
	Moment resisting frame with unreinforced masonry infill walls
	Moment resisting frame flat slab structure
	Shear walls cast in-situ
Masonry	Confined brick/block masonry with concrete posts/tie columns and beams
	Unreinforced brick masonry in cement mortar with reinforced concrete floor/roof slabs
Steel	Moment resisting frame with cast in-situ concrete walls
	Moment resisting with light weight partitions
	Concrete braced frame
Wooden	Pre-1981
	Post-1981

According to residential housing type data, buildings are categorized in four basic categories as reinforced concrete, masonry, steel and wooden. These building types are further divided into sub-types depending upon load resisting system.

2.2.8 Nepal

For seismic vulnerability assessment of buildings in the Kathmandu city of Nepal, the following structural parameters have been considered for building classification (MRB and Associates, 2010).

i) Material of Construction
ii) Type of Load Bearing Structure
iii) Lateral Load Resisting System
iv) Quality of Construction

On the basis of above parameters, following building typologies have been defined as given in Table 2.20.

Table 2.20: Building Typologies in Kathmandu, Nepal (MRB and Associates, 2010)

No.	Building Types in Kathmandu Valley	Description
1	Adobe, stone in mud, brick-in-mud (Low Strength Masonry).	Adobe Buildings: These are buildings constructed in sun-dried bricks (earthen) with mud mortar for the construction of structural walls. The walls are usually more than 350 mm. Stone in Mud: These are stone-masonry buildings constructed using dressed or undressed stones with mud mortar. These types of buildings have generally flexible floors and roof. Brick in Mud: These are the brick masonry buildings with fired bricks in mud mortar.
2	Brick in Cement, Stone in Cement	These are the brick masonry buildings with fired bricks in cement or lime mortar and stone-masonry buildings using dressed or undressed stones with cement mortar.
3	Reinforced Concrete Ordinary-Moment-Resisting-Frame Buildings	These are the buildings with reinforced concrete frames and unreinforced brick masonry infill in cement mortar. The thickness of infill walls is 230mm (9”) or even 115mm (41/2”) and column size is predominantly 9”x 9”. The prevalent practice of most urban areas of Nepal for the construction of residential and commercial complexes is generally of this type.
4	Reinforced Concrete Intermediate-Moment-Resisting-Frame Buildings	These buildings consist of a frame assembly of cast-in-place concrete beams and columns. Floor and roof framing consists of cast-in-place concrete slabs. Lateral forces are resisted by concrete moment frames that develop their stiffness through monolithic beam-column connections. These are engineered buildings designed without earthquake load or with old codes or designed for small earthquake forces. Some of the newly constructed reinforced concrete buildings are likely to be of this type.
5	Reinforced concrete special-moment-resistant frames (SMRF)	These buildings consist of a frame assembly of cast-in-place concrete beams and columns. Floor and roof framing consists of cast-in-place concrete slabs. Lateral forces are resisted by concrete moment frames that develop their stiffness through monolithic beam-column connections. These buildings have joint reinforcing, closely spaced ties, and special detailing to provide ductile performance. Despite the fact that this system should be adopted ideally for all new RC frame buildings in Nepal, it is now only used as an exception.
6	Others	Mixed buildings like Stone and Adobe, Stone and Brick in

No.	Building Types in Kathmandu Valley	Description
		Mud, Brick in Mud and Brick in cement etc. are other building type in Kathmandu valley.

Table 2.20 classifies buildings into 6 broad categories. Each building typology has been described in further detail. The seismic risk assessment of Kathmandu city in Nepal has been carried out using this building typology and its associated vulnerability assessment.

2.2.9 New Zealand

The building classification used in New Zealand has been presented in Uma et al. (2008). This gives classification of buildings in terms of structural type or material of construction of the building, Structural form (complexity) and height of the building.

In New Zealand residential buildings are mostly low-rise timber buildings, accommodating single families, and apartments with multiple families. Commercial buildings used as offices, public services, and hospitals range from low to high-rise buildings constructed from timber, reinforced concrete and steel. The structural forms can be moment resisting frame in one direction and shear wall in the other direction or with core shear walls taking lateral loads and gravity frames on the exterior. Most of the buildings are constructed with shear walls. Industrial buildings featuring factories and warehouses are typically low-rise with steel moment resisting or portal frame structural forms and cross bracing in the other direction. There are a number of buildings with precast walls using tilt-up construction (Uma et al., 2008).

The distribution of buildings based on construction material is given in Table 2.21.

Table 2.21: New Zealand Building Classification (Uma et al., 2008)

Material	Structural Form	Height of the Building	Class
Wood	Light Timber Frame	Low Rise	W(L)
Masonry	Unreinforced Masonry	Low Rise	URM(L)
	Block Masonry	Low Rise	RM (L)
Reinforced Concrete	Moment Resisting Frame	Low Rise	CF(L)
		Medium Rise	CF(M)
		High Rise	CF(H)
	Shear Wall	Low Rise	CSW(L)
		Medium Rise	CSW(M)
		High Rise	CSW(H)
Steel	Moment Resisting Frame	Low Rise	SF(L)
		Medium Rise	SF(M)
		High Rise	SF(H)
	Portal Frame-braced	Low Rise	SPF(L)

Material	Structural Form	Height of the Building	Class
	Braced Frame	Low Rise	SBR(L)
		Medium Rise	SBR(M)
		High Rise	SBR(H)
Precast Concrete	Tilt-up	Low Rise	T(L)

Table 2.21 presents the various building classes defined for New Zealand buildings. As with many other classification systems, as can be seen from the table this classification also uses construction material, load resisting system and height of the building as basic parameters for categorization of buildings.

2.2.10 Portugal

Every 10 years, Portuguese building census is carried out. Specific questions such as seismic vulnerability and building conservation status were addressed during 2001 building census. The predominant building typologies which were observed in this survey are listed below in Table 2.22.

Table 2.22: Building Typology in Portugal as per Portugal Housing census stock (Costa and Sousa, 2011)

Sr. No.	Material	Structural Type	Sub-type
1.	Masonry	Traditional Construction	
		Old Buildings (Urban)	Before 1755
			Pombalinos
			Gaioleiros
		Masonry with RC Floors	Unreinforced masonry with RC floors “Placa”
			Confined masonry
		Unreinforced stone or brick masonry with wooden floors	—
		Adobe, "taipa", or rubble stone masonry without mortar (old rural houses)	—
2.	RC	RC frame	Without ERD
			After RSCCS code and before RSA code
			After RSA code

Sr. No.	Material	Structural Type	Sub-type
		RC wall	
		RC frame-wall structual system	
3.	Wooden structures		
4.	Steel frames		

2.2.11 SAARC Countries

A report has been prepared by Prof. A.S. Arya for building typologies used in school and health buildings in South Asian Association of Regional Cooperation (SAARC) countries. The report considered that there will be varying typologies in rural and urban areas, somewhat similar to residential building technologies. The nomenclature used for various buildings as used in FEMA 154, except some building types used in USA whose similar buildings are not apparently used in SAARC countries. Thus, building typologies in SAARC countries are listed in Tables 2.23, 2.24 and 2.25. Table 2.25(a) gives the description of various roof types which are used in classification of buildings.

Table 2.23: Building Typologies – Clay, Stone and Wood buildings (Arya, 2011)

Sr. No.	Wall Material	Description of construction	Roof Type	Floor if any	Designation in FEMA 154	Designation in Arya's RVS
1.	Clay (Cl1)	Walls constructed on ground or shallow foundation	Pitched &Flexible	Flat & Flexible	Nil	A
			Flat & Flexible			
			Flat & rigid			
	Adobe &Unburnt brick (Cl2)	Walls constructed on ground or shallow foundation	Pitched &Flexible	Flat & Flexible	Nil	A+
			Flat & Flexible			
2.	Stone (ST1)	Random Rubble, dry construction or with mud mortar	Pitched &Flexible	Flat & Flexible	Nil	A+
			Flat & Flexible			
	Stone (ST2)	As above with horizontal wooden dovels	Pitched &Flexible	Flat & Flexible	Nil	B
			Flat & Flexible			
			Flat & rigid			

Sr. No.	Wall Material	Description of construction	Roof Type	Floor if any	Designation in FEMA 154	Designation in Arya's RVS
	Stone (ST3)	Dressed stone laid in good lime mortar/ cement mortar	Pitched & Flexible	Flat & Rigid	Nil	B+
			Flat & Rigid			
	Stone (ST4)	As ST2 with horizontal wood runners used as bands or RC bands	Pitched & Flexible	Flat & Rigid	Nil	C
			Flat & Rigid			
3.	Wood (WD1)	Wattle & daub	Pitched & Flexible		Nil	B
	Wood (WD2)	Assam Type Stud wall with Ikra wall panels	Pitched & Flexible		W1/W2	D
	Wood (WD3)	Wood frame with brick nogging (DhajjiDiwari)	Pitched & Flexible	Flat & Flexible	Nil	C+
	Wood (WD4)	wood stud wall with wood or metal siding	Pitched & Flexible	Flat & Flexible	W1/W2	D

Table 2.24: Building Typologies – Burnt Brick & Cement Concrete Block buildings (Arya, 2011)

Sr. No.	Wall Material	Description of construction	Roof Type	Floor if any	Designation in FEMA 154	Designation in Arya's RVS
1.	Burnt brick walls in mud mortar	Burnt brick walls in mud mortar	Pitched & Flexible	Flat & Flexible	Nil	B
			Flat & Flexible	Flat & Rigid		
			Flat & Rigid			
	Burnt brick	Burnt brick walls in	Pitched & Flexible	Flat & Rigid	URM	B+

Sr. No.	Wall Material	Description of construction	Roof Type	Floor if any	Designation in FEMA 154	Designation in Arya's RVS
	(BB2)	ordinary lime mortar	Flat &Flexible			
			Flat & Rigid			
	Burnt brick (BB3)	Burnt brick walls in good cement mortar	Pitched & Flexible	Flat & Rigid	URM	C
			Flat & Rigid			
	Burnt brick (BB4)	Similar to BB3 with RC Seismic Bands	Pitched & Flexible	Flat & Rigid	URM	C+
			Pitched & Rigid			
			Flat & Rigid			
	Burnt brick (BB5)	Similar to BB3 but with seismic bands & vertical reinforcements at corners and jambs of openings or confined masonry	Pitched & Rigid	Flat & Rigid	RM1	D
			Flat & Rigid		RM2	
	Burnt brick (BB6)	Reinforced masonry walls	Pitched & Rigid	Flat & Rigid	Nil	D+
			Flat & Rigid		RM2	
2.	Cement Concrete block (CC1) (Solid/ hollow)	CC blocks with cement mortar	Pitched & Flexible Pitched & Rigid Flat & Rigid	Flat & Rigid	URM	C
	Cement Concrete	As CC1 but with	Pitched & Flexible	Flat & Rigid	URM	C+

Sr. No.	Wall Material	Description of construction	Roof Type	Floor if any	Designation in FEMA 154	Designation in Arya's RVS
	block (CC2) (Solid/ hollow)	seismic bands	Pitched &Rigid Flat & Rigid			
	Cement Concrete block (CC3) (Solid/ hollow)	As CC2 with vertical steel at corners	Pitched & Flexible Pitched & Rigid Flat & Rigid	Flat & Rigid	RM1	D
			Flat & Rigid		RM2	

Table 2.25: Building Typologies – Reinforced Concrete and Steel Frame buildings (Arya, 2011)

Sr. No.	Wall Material	Description of construction	Roof Type	Floor if any	Designation in FEMA 154	Designation in Arya's RVS
1.	Reinforced Concrete (RC1)	Non-engineered beam post construction with unreinforced brick infill walls	Flat & Rigid	Flat & Rigid	C3	C
2.	Reinforced Concrete (RC2)	Prefabricated reinforced concrete building	Flat & Rigid	Flat & Rigid	Nil	C+
3.	Reinforced Concrete (RC3)	Moment Resistant Reinforced Concrete frame of ordinary design with unreinforced masonry infill	Flat & Rigid	Flat & Rigid	Nil	C+
4.	Reinforced Concrete (RC4)	Moment resistant RC frame with	Flat & Rigid	Flat & Rigid	Nil	D

Sr. No.	Wall Material	Description of construction	Roof Type	Floor if any	Designation in FEMA 154	Designation in Arya's RVS
		ordinary earthquake resistant design without ductility details with unreinforced masonry infill				
5.	Reinforced Concrete (RC5)	Moment resistant RC frame with earthquake resistant design and special ductility details with unreinforced masonry infill	Flat & Rigid	Flat & Rigid	Nil	E
6.	Reinforced Concrete (RC6)	Same as RC5 but with well designed infill walls	Flat & Rigid	Flat & Rigid	Nil	E+
7.	Reinforced Concrete (RC7)	Moment resistant RC frame with earthquake resistant design with special ductility details and shear walls	Flat & Rigid	Flat & Rigid	C2	F
8.	Steel Frame (SF1)	Steel frame without bracings having hinged joints	Pitched & Flexible	Flat & Flexible	Nil	C
9.	Steel Frame (SF2)	Steel frame of ordinary design with unreinforced	Pitched & Flexible Flat	Flat & Flexible Flat &Rigid	S5	C+

Sr. No.	Wall Material	Description of construction	Roof Type	Floor if any	Designation in FEMA 154	Designation in Arya's RVS
		masonry infill	& Flexible Flat & Rigid			
10.	Steel Frame (SF3)	Moment resistant steel frame without bracings & without plastic design details	Flat & Rigid	Flat & Rigid	Nil	C+
11.	Steel Frame (SF4)	Moment resistant steel frame with ordinary ERD without special details	Flat & Rigid	Flat & Rigid	Nil	D
12.	Steel Frame (SF5)	Moment resistant steel frame with high level earthquake resistant design and special plastic design details/steel braces	Flat & Rigid	Flat & Rigid	Nil	E
13.	Steel Frame (SF6)	Ordinary steel frame with braces	Flat & Rigid	Flat & Rigid	S2	E+
14.	Steel Frame (SF7)	Steel frames with cast in place shear walls	Flat & Rigid	Flat & Rigid	S4	F

Table 2.25(a): Description of Roof Types (Arya, 2011)

Sr. No.	Roof Type	Description
1.	Pitched & Flexible	Sloping roofs with tiles, slates or shingle corrugated iron. Corrugated galavanised iron sheets or asbestos cement sheets or thatch, grass, leaves, bamboo etc.
2.	Pitched & Rigid	Reinforced Cement Concrete sloping slabs
3.	Flat & Flexible	Wooden logs or joists with reeds & bushes covered with earth /wooden joist with bricks & stone slabs
4.	Flat & Rigid	Reinforced brick concrete/Reinforced Cement Concrete/Jack Arch floor/roof

2.2.12 Switzerland

In order to assess the seismic risk for Switzerland, and particularly for the city of Basel, the seismic vulnerability of the existing buildings has been evaluated (Lang and Bachmann, 2004). The following parameters were considered to classify buildings into various categories.

i) Material of Construction
ii) Height of the Building
iii) Structural Element

On the basis of above characteristics, Table 2.26 presents the various building typologies in Basel, Switzerland considered for seismic risk assessment.

Table 2.26: Building Typologies in Basel, Switzerland (Lang and Bachmann, 2004)

ID	Building Typologies
Low-rise URM	Unreinforced Masonry Buildings with Timber Floors- Low Rise
Mid-rise URM	Unreinforced Masonry Buildings with Timber Floors- Medium Rise
Mid-rise URM + RC	Mixed system of vertical reinforced concrete elements combined with unreinforced masonry elements- Medium Rise

As seen in Table 2.26, only three building classes have been defined for the city of Basel based on the prevalent construction practice in the city. It is seen from the table that there are no classifications using steel, and the buildings are categorized into unreinforced masonry or unreinforced masonry with some reinforced concrete elements.

2.2.13 Taiwan

Information regarding total housing stock distribution in Taiwan exists in the form of householder registration data, but it is not accessible. Nevertheless, the housing stock distribution for most of the affected areas after the Chi-Chi earthquake is well documented and gives detailed information. The building stock distribution available for Nantau and Taichung County (Tien et al., 2002) is shown in Table 2.27.

Table 2.27: Residential Building Types in Taiwan (Tien et al., 2002)

ID	Building Types
A	Mud-brick
M	Masonry and Reinforced Masonry
RC	Reinforced Concrete Building
S	Steel Frames
COM	Composite Construction (Steel and RC)
	Others

The building types defined in Table 2.27 are mainly based on material of construction. The classification is very general and does not specify particular structural characteristics of buildings.

2.2.14 Turkey

According to Building Inventory Data used in Seismic Risk Studies in Turkey (Erdik, 2011), buildings are classified on the basis of following characteristics.

i) Material of Construction,
ii) Lateral Load Resisting System
iii) Height of the Building
iv) Quality of Construction

These building types are described in Table 2.28.

Table 2.28: Building Types in Turkey (Erdik, 2011)

Material Type	Sub Type	Height of the Building	Construction Year	ID
Unreinforced Masonry	Rubble Stone	Low-Rise	Pre-1979 or Post-1979	M1
		Mid-Rise		
		High-Rise		
	Adobe (earth bricks)	Low-Rise	Pre-1979 or Post-1979	M2
		Mid-Rise		
		High-Rise		
	Simple Stone	Low-Rise	Pre-1979 or	M3

Material Type	Sub Type	Height of the Building	Construction Year	ID
		Mid-Rise	Post-1979	
		High-Rise		
	Massive Stone	Low-Rise	Pre-1979 or Post-1979	M4
		Mid-Rise		
		High-Rise		
	U Masonry (old bricks)	Low-Rise	Pre-1979 or Post-1979	M5
		Mid-Rise		
		High-Rise		
	U Masonry (R.C. floors)	Low-Rise	Pre-1979 or Post-1979	M6
		Mid-Rise		
		High-Rise		
Reinforced/Confined Masonry	Reinforced/Confined Masonry	Low-Rise	Pre-1979 or Post-1979	M7
		Mid-Rise		
		High-Rise		
Reinforced Concrete	Concrete Moment Frame	Low-Rise	Pre-1979 or Post-1979	RC1
		Mid-Rise		
		High-Rise		
	Concrete Shear Walls	Low-Rise	Pre-1979 or Post-1979	RC2
		Mid-Rise		
		High-Rise		
	Dual System	Low-Rise	Pre-1979 or Post-1979	RC3
		Mid-Rise		
		High-Rise		
Steel Typologies	Steel Typologies	Low-Rise	Pre-1979 or Post-1979	S
		Mid-Rise		
		High-Rise		
Timber Typologies	Timber Typologies	Low-Rise	Pre-1979 or Post-1979	W
		Mid-Rise		
		High-Rise		

It is seen in Table 2.28 that the building classification is quite comprehensive. It also specifies unique code for each building type. The year of construction in the Table is used for determination of quality of construction and compliance with more stringent requirements.

Buildings constructed before 1979 are considered as having less material strength and low compliance with code is assumed.

2.3 Comparison of Building Typologies

Since building typology is an important requirement for assessing seismic hazard of a country or a region, considerable research and development has been undertaken in this field. The recommendations in published literature are based on combinations of material of construction and structural parameters that influence the seismic resistance of a building. While some building typology recommendations consider the requirement for damage intensity assessment following an earthquake, others consider the requirement from seismic hazard assessment requirements. An assessment of some important recommendations such as FEMA 310 (Federal Emergency Management Agency), EMS 98 (European Macroseismic Scale), HAZUS (Hazard US), MSK-64, PAGER (Prompt Assessment of Global Earthquakes for Response), RISK-UE, and Coburn and Spence (2002) have been presented in this section.

MSK-64 scale is one of the earliest scales still in use, which defines building typologies for seismic intensity assessment. This scale is based on the Mercalli Intensity scale developed around a hundred years ago. It broadly categorizes buildings by type of construction as a simple attempt to express the damageability of buildings to earthquake ground motions.

EMS 98 focuses more on choice of building material used than its force-resisting system. It provides not only building classification type but also basic vulnerability class with range of possible values. It is the only specification with such feature. The vulnerability classes range from A to F, with A indicating highest vulnerability and F indicating highest resistance. There are total six classes for each range for each type. The buildings are divided into four groups, which are further subdivided into 10 subgroups making a total of 33 types. There is no separate group for prestressed concrete constructions and is included within concrete group.

The primary parameter of interest of FEMA 310 is the lateral force resisting system and the type of diaphragm used in that structure. A diaphragm is defined as that horizontal system configuration which serves to transit forces to vertical resisting system. Lateral force resisting system mainly consists of frame, shear wall, bearing wall, braced frame and interconnected horizontal diaphragm. Two different types are possible for the same building depending on direction of excitation chosen. FEMA 310 can give two different vulnerability classifications for the same building in two orthogonal directions. This is very helpful for building with in-plan or structural irregularities. It classifies building into five groups and then into 15 subgroups giving a total of 23 types.

HAZUS gives more weightage to structural parameters affecting capacity and response which can be basic structural system like structural frames etc., building height and seismic design criteria's like seismic zones. It also takes into account non-structural elements affecting functional elements, occupancy of building, regional building preferences and variability of characteristics within the classification. The HAZUS classification has a two dimensional matrix relating basic structural system with occupancy class. It divides structural configurations in building into 5 groups and then into 15 subgroups making a total of 35 types. It classifies building occupancy classes into 7 primary groups and then into 28 subgroups. Mapping between these two classifications is carried out using this matrix. The HAZUS building typology includes a special structure class for mobile home.

The inventory data needs of PAGER have a much wider geographic scope than considered in previous studies. Hence, a number of techniques and processes were considered before a consensus is made to satisfy regional needs and data constraints. For example, in order to estimate the fraction of building types, it was necessary to classify the worldwide building types broadly based on predominant construction material used for the construction of the walls and their structural systems. The choice of limited categories for building types was mainly due to lack of sufficient information about structural systems, and the limited scientific information about performance of such building types during strong shaking. Owing to paucity of data, buildings have been broadly classified into residential and non-residential types based on functional use mainly due to wide variation of occupancy characteristics between these two broad occupancy categories during day and night time. It gives very comprehensive classification of buildings as compared to other studies as it considers various construction types prevalent in different parts of the world.

The World Housing Encyclopedia (WHE) database covers 110 housing types (as of Jan. 10, 2007) contributed by 180 volunteer engineers and architects from various countries and regions. The database contains a comprehensive global categorization of characteristic housing construction types across the world. The housing type report includes all relevant aspects of housing construction, such as socio-economic issues, architectural features, structural system, seismic deficiencies and earthquake-resistant features, performance in past earthquakes, available strengthening technologies, building materials used, construction process employed, and insurance conditions. In addition to the structure-specific information, several illustrative photos, drawings, sketches are also included in the report. However, despite such elaborate information, the WHE database does not contain inventory and vulnerability-specific information for all the structure types.

Coburn and Spence (2002) present a general classification of construction types found in many seismically active areas of the world. They have listed the building types based on their seismic vulnerability. The vulnerability of these construction types can be expected to decrease from top to bottom of the list. For example, earth and rubble stone buildings which are at the top of this list, are most vulnerable and would be expected to suffer most damage in point of view of building response.

The various building classification methods from seismic vulnerability assessment considerations used in some countries have been described in Table 2.11 to Table 2.28 It is seen that major parameters considered for the building classification are material of construction, load resisting system, height of the building and quality of construction. Seismic performance of the buildings in different countries can be different due to local factors, even though these buildings are classified into same category by various methods.

The building classification methods used across most of the countries have been adopted from the above discussed building typology models (FEMA, PAGER, EMS-98, etc.).

In Australia, building typologies are defined into three categories depending upon whether the building is made of masonry, timber or reinforced concrete. The classification system used in Australia is not suitable for seismic risk assessment.

For different cities in Canada, a comprehensive building typology classification method has been developed. There are 31 building types defined for Canada. Each building type is given a unique code as per the various parameters considered for the classification. These building typologies have been used for seismic vulnerability assessment of various cities in Canada such as Vancouver and Quebec City.

There are six building categories specified for seismic risk assessment of Kathmandu Valley, Nepal. The buildings have been mainly classified based on material of construction. Each building type has been explained in detail so that the classification based on field surveys can be carried out with minimum error.

In case of Japan, buildings are categorized into four basic categories, viz. reinforced concrete, masonry, steel and timber. The data used for the classification is mainly residential housing type data. These building types are further divided into sub-types depending upon load resisting system.

As with many other classification systems, New Zealand building classification also uses construction material, load resisting system and height of the building as basic parameters for categorization of buildings.

Based on prevalence of construction, three building classes have been specified for the city of Basel, Switzerland. In this building classification, steel constructions are not included. A very basic classification of buildings is done by placing them into unreinforced masonry or unreinforced masonry with some reinforced concrete elements.

Building types used for Taiwan following the 1999 earthquake are very simple and based on material of construction. The classification scheme is very general and does not describe structural characteristics of the buildings.

Turkey building typology classification is very detailed and comprehensive. It also specifies unique code for each building type. The classification also uses year of construction as one of the parameters to categorize the building. The year of construction is used for determination of quality of construction. Buildings before 1979 are considered as having lower material strength and low compliance with code.

The comparison of various methodologies of building classification based upon building parameters discussed in this section is presented in Table 2.29. Table 2.29 (a) to 2.29 (k) show the comparison of various building types based upon the building material.

Table 2.29: Comparison of various Building Typologies

	FEMA 310	WHE-EERI	HAZUS	PAGER	EMS98	Coburn & Spence 2002	RISK-UE
Primary Parameters of interest	1. Building material 2. Lateral force resisting system 3. diaphragm type	Choice of building material	1. Building material 2. Structural Parameters affecting capacity and response 3. Basic Structural system(frame) 4. Building Height 5. Seismic design criteria 6. Non-structural elements 7. Occupancy 8. Regional building preferences 9. Variability of characteristics within classification	1. Building material 2. Vertical framing system 3. Horizontal framing system 4. Roof/floor system 5. Number of storeys	Choice of Building material	1. Non-engineered and engineered buildings 2. Building material	Building material
Salient features	Two different types possible for one building for two directions	Building type as well as basic vulnerability class with range of values	Two Dimensional matrix relating basic structural system and occupancy classes.	Very detailed classification for each material type	Building type as well as basic vulnerability class with range of values	Categorizes buildings from most vulnerable to least vulnerable	Incorporates the characteristic features of European building taxonomy

Table 2.29(a): Comparison of various Building Typologies: Wood

Wood	FEMA 310	WHE-EERI	HAZUS	PAGER	EMS98	Coburn & Spence 2002	RISK-UE
Light Frame	One or more stories with light loads and the short framing spans. Lateral forces are resisted by wood frame diaphragms and shear walls. Floor and roof diaphragms consist of straight or diagonal wood sheathing, tongue and groove planks, or plywood. Shear walls consist of straight or diagonal wood sheathing, plank siding, plywood, stucco, gypsum board, particle board, or fibre board.	Frame with stud walls Frame with plywood/gypsum board sheathing Frame with (stone/brick) masonry infill Walls with bamboo/reed mesh and post (Wattle and Daub) Post and beam frame Thatch roof	Class W1 (< 5,000sq.ft.)	Wood Frame, Wood Stud, Wood, Stucco, or Brick Veneer (W1) Wood Frame, Heavy Members, Diagonals or Bamboo Lattice, Mud Infill (W2)	Timber Structures (W)	Timber frame with timber cladding, lightweight structures (CT2)	Wood Structures (W)
	Multi-story and multi-unit residences. First story consists of wood floor framing on wood stud walls and steel pipe columns, or a concrete slab on concrete or concrete masonry block walls.						
Industrial Frame	Buildings with a floor area of 5,000 square feet or more with heavier building loads and long framing spans. Lateral forces are resisted by wood diaphragms and exterior stud		Class W2 (>= 5,000sq.ft.)	Wood Frame, Prefabricated Steel Stud Panels, Wood or Stucco Exterior Walls (W3)		Timber frame with heavy infill masonry (CT1)	

Table 2.29(b): Comparison of various Building Typologies: Steel

Steel	**FEMA 310**	**WHE-EERI**	**HAZUS**	**PAGER**	**EMS98**	**Coburn & Spence 2002**	**RISK-UE**
Moment Frame	Frame assembly of steel beams and steel columns with cast-in-place concrete slabs or metal deck. Lateral forces are resisted by steel moment frames that develop their stiffness through rigid or semi-rigid beam-column connections. Diaphragms consist of concrete or metal deck with concrete fill and are stiff relative to the frames.	With brick masonry partitions	Low Rise(1-3) Mid Rise(4-7) High Rise(8+)	Low Rise (S1L) Mid Rise (S1M) High Rise (S1H)	Steel Structures (S)	Steel frame, moment resistant (DS2)	Steel moment frame (S1)
	Diaphragms consist of wood framing or untapped metal deck, and are flexible relative to the frames.						
Braced Frame	Frame assembly of steel beams and steel columns with cast-in-place concrete slabs Lateral forces resisted by tension and compression forces in diagonal steel members. Diaphragms of concrete or metal deck with concrete fill, stiff relative to the frames.	With various floor/roof systems	Low Rise(1-3) Mid Rise(4-7) High Rise(8+)	Low Rise (S2L) Mid Rise (S2M) High Rise (S2H)	Steel Structures (S)	Steel frame, braced (DS4)	Steel braced frame (S2)
	Diaphragms of wood framing or untapped metal deck, flexible relative to the frames						

Table 2.29(c): Comparison of various Building Typologies: Steel

Steel	FEMA 310	WHE-EERI	HAZUS	PAGER	EMS98	Coburn & Spence 2002	RISK-UE
Light Moment Frame	Pre-engineered one-story buildings along with roof and walls consisting of lightweight metal, fiberglass or cementitious panels. Lateral forces in the transverse direction are resisted by the rigid frames while in the longitudinal direction by wall panel shear. Diaphragm forces are resisted by untapped metal deck, roof panel shear elements, or a system of tension-only rod bracing.	Single storey LM frame structure	Low Rise(1-3) Mid Rise(4-7) High Rise(8+)	Steel Light Frame (S3)	Steel Structures (S)	Light steel frame (DS1)	---------
Frames With Concrete Shear Walls	Frame assembly of steel beams and steel columns with cast-in-place concrete slabs or metal deck. Lateral forces are resisted by cast-in-place concrete shear walls. Diaphragms consist of concrete or metal deck with or without concrete fill. Steel frame may provide a secondary lateral-force-resisting system.	With cast in-situ concrete walls	Low Rise Mid Rise High Rise	Low Rise (S4L) Mid Rise (S4M) High Rise (S4H)	Steel Structures (S)	Steel frame with RC shear wall or core (DS5)	Steel frame with cast in place shear walls (S4)
Frame With Infill Masonry Shear walls	Frame assembly of steel beams and steel columns with cast-in-place concrete slabs or metal deck with concrete fill. Walls consist of infill panels constructed of solid clay brick, concrete block, or hollow clay tile masonry. The diaphragms consist of concrete floors and are stiff relative to the walls.	-----------	Low Rise Mid Rise High Rise	Low Rise (S5L) Mid Rise (S5M) High Rise (S5H)	Steel Structures (S)	Steel frame with infill masonry (DS3)	Steel frame unreinforced masonry infill walls (S3)

Table 2.29(d): Comparison of various Building Typologies: Concrete

Concrete	FEMA 310	WHE-EERI CLASS	HAZUS	PAGER	EMS98	Coburn & Spence 2002	RISK-UE
Moment Frame	Frame assembly of cast-in-place concrete beams and columns. Lateral forces are resisted by concrete moment frames that develop their stiffness through monolithic beam-column connections.	Designed for gravity loads only (predating seismic codes i.e. no seismic features) Designed with seismic features Flat slab structure	Low Rise(1-3) Mid Rise(4-7) High Rise(8+)	Low Rise (C1L) Mid Rise (C1M) High Rise (C1H)	1. Frame without Earthquake-Resistant Design (ERD) 2. Frame with moderate level of ERD 3. Frame without high level of ERD	In-situ RC frame with non-structural cladding (DC1)	Concrete Moment Frame (RC1)
Frame with shear wall	Floor and roof framing that consists of cast-in-place concrete slabs, concrete beams, one-way joists, two-way waffle joists, or flat slabs. Floors are supported on concrete columns or bearing walls. Lateral forces are resisted by cast-in-place concrete shear walls. Diaphragms consist of concrete slabs and are stiff relative to the walls.	Walls cast in-situ Precast wall panel structure	Low Rise Mid Rise High Rise	Low Rise (C2L) Mid Rise (C2M) High Rise (C2H)	1. Walls without ERD 2.Walls with moderate level of ERD 3.Walls with high level of ERD	In-situ RC frame with shear wall (DC3)	Concrete Shear Walls (RC2)

Table 2.29(e): Comparison of various Building Typologies: Concrete

Concrete	FEMA 310	WHE-EERI CLASS	HAZUS		EMS98	Coburn & Spence 2002	RISK-UE
Frame with infill masonry shear wall	The diaphragms consist of concrete floors and are stiff relative to the walls Diaphragms consist of wood sheathing, or have large aspect ratios, and are flexible relative to the walls. Walls consist of infill panels constructed of solid clay brick, concrete block, or hollow clay tile masonry. The seismic performance of this type of construction depends on the interaction between the frame and infill panels.	Frame with unreinforced masonry infill walls	Low Rise(1-3) Mid Rise(4-7) High Rise(8+)	Low Rise (C3L) Mid Rise (C3M) High Rise (C3H)	--------	In-situ RC frame with infill masonry wall (DC2)	Concrete frames with unreinforced masonry regularly infill walls (RC3.1)/ irregularly infill walls (RC3.2)
Precast Concrete frames With shear Wall	One or more stories Framing supported on interior steel columns and perimeter concrete bearing walls with the floors and roof consist of wood sheathing or untapped metal deck. Lateral forces are resisted by the precast concrete perimeter wall panels. Wall panels may be solid, or have large window and door openings which cause the panels to behave more as frames than as shear walls. Wood framing is attached to the walls with wood ledgers.	Precast frame structure with concrete shear walls (dual system)	Low Rise(1-3) Mid Rise(4-7) High Rise(8+)	Low Rise (PC2L) Mid Rise (PC2M) High Rise (PC2H)	--------	Precast RC frame with infill masonry (DP1) Precast RC frame with concrete shear wall (DP2)	Precast concrete frame concrete shear walls (RC6)

Table 2.29(f): Comparison of various Building Typologies: Concrete

Concrete	FEMA 310	WHE-EERI CLASS	HAZUS	PAGER	EMS98	Coburn & Spence 2002	RISK-UE
Precast concrete frame	Frame assembly of precast concrete girders and columns. Floor and roof framing consists of precast concrete planks, tees supported on precast concrete girders and columns. Lateral forces are resisted by precast or cast-in-place concrete shear walls. Diaphragms consist of precast elements interconnected with welded inserts, cast-in-place closure strips, or reinforced concrete topping slabs. Concrete shear walls are not present. Lateral forces are resisted by precast concrete moment frames Diaphragms consist of precast elements interconnected with welded inserts, cast-in-place closure strips, or reinforced concrete topping slabs.	Precast Concrete Frame	Low Rise(1-3) Mid Rise(4-7) High Rise(8+)	Precast Concrete Tilt-Up Walls (PC1)	--------	Precast large panel structure (DP3)	Precast concrete tilt-up walls

Table 2.29(g): Comparison of various Building Typologies: Masonry (Engineered)

Masonry	FEMA 310	WHE-EERI	HAZUS	PAGER	EMS98	Coburn & Spence 2002	RISK-UE
Engineered Structures using Reinforced brick/ concrete block	Diaphragms consist of straight or diagonal wood sheathing, plywood, and are flexible relative to the walls. Steel floor and roof framing consists of steel beams or open web joists, steel girders and steel columns. Lateral forces are resisted by shear walls.	Unreinforced, in lime/cement mortar (various floor/roof systems)	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms Low Rise(1-3) Mid Rise(4-7) High Rise(8+)	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms (RM1) Low Rise (RM1L) Mid Rise (RM1M)	Unreinforced with R.C. Floors	Reinforced Brick Masonry (DB1)	Reinforced or confined masonry walls (M4)
	Diaphragms consist of metal deck with concrete fill, precast concrete planks, tees, a cast-in-place concrete topping slab, and are stiff relative to the walls. The floor and roof framing is supported on interior steel or concrete frames or interior reinforced masonry walls.	Reinforced, in cement mortar (various floor/roof systems)	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms Low Rise(1-3) Mid Rise(4-7) High Rise(8+)	Reinforced Masonry Bearing Walls with Concrete Diaphragms (RM2) Low Rise (RM2L) Mid Rise (RM2M) High Rise (RM2H)	Reinforced/Confined Masonry	Reinforced Brick Masonry (DB1)	Unreinforced masonry bearing walls with reinforced concrete slabs (M3.4)

Table 2.29(h): Comparison of various Building Typologies: Masonry (Non-Engineered)

Masonry	FEMA 310	WHE-EERI	HAZUS	PAGER	EMS98	Coburn & Spence 2002	RISK-UE
Non-Engineered Structures	Construction floor and roof framing consists of straight or diagonal lumber or plywood sheathing supported by wood joists, on posts. The diaphragms are flexible relative to the walls. They ties between the walls and consist of bent steel plates or anchors.	Confined brick/block masonry with concrete posts columns and beams	Unreinforced Masonry Bearing Walls Low Rise(1-2) Mid Rise(3+)	Mud Walls without Horizontal Wood Elements (M1)	Rubble Stone, Fieldstone	Rubble Stone in mud or lime mortar (AR1)	Rubble stone, fieldstone (M1.1)
		Unreinforced brick masonry in cement mortar with lintel bands (various floor/roof systems)		Adobe Block with Mud Mortar, Wood Roof and Floors (A1) / Bamboo, Straw, and Thatch Roof(A2) / Cement-Sand Mortar (A3)/ Reinforced Concrete Bond Beam, Cane and Mud Roof(A4)/ Bamboo or Rope Reinforcement (A5)	Adobe (earth brick)	Rammed Earth Construction (AE1)	Simple stone (M1.2)
		Unreinforced brick masonry in cement mortar with reinforced concrete floor/roof slabs		Rammed Earth/Pneumatically Impacted Stabilized Earth (RE)	Simple Stone	Composite Earth with Timber or Fibre, earth and bamboo (AE2)	Massive stone (M1.3)

Table 2.29(i): Comparison of various Building Typologies: Masonry (Non-Engineered)

Masonry	FEMA 310	WHE-EERI	HAZUS	PAGER	EMS98	Coburn & Spence 2002	RISK-UE
Non-Engineered Structures	Construction floor and roof framing consists of straight or diagonal lumber or plywood sheathing supported by wood joists, on posts. The diaphragms are flexible relative to the walls. They ties between the walls and consist of bent steel plates or anchors	Unreinforced brick masonry in lime mortar	Unreinforced Masonry Bearing Walls Low Rise(1-2) Mid Rise(3+)	Rubble Stone (Field Stone) Masonry Local Field Stones Dry Stacked (No Mortar). Timber Floors. Timber, Earth, or Metal Roof (RS1)	Massive Stone	Adobe sun-dried earth brick in mud mortar (AA1)	Adobe(M2)
				Same as RS1 with Mud Mortar (RS2)			
				Same as RS1 with Lime Mortar (RS3)			
				Same as RS1 with Cement Mortar, Vaulted Brick Roof and Floors (RS4)			
				Same as RS1 with Cement Mortar and Reinforced Concrete Bond Beam (RS5)			

Table 2.29(j): Comparison of various Building Typologies: Masonry (Non-Engineered)

Masonry	FEMA 310	WHE-EERI	HAZUS	PAGER	EMS98	Coburn & Spence 2002	RISK-UE
Non-Engineered Structures	Diaphragms are stiff relative to the unreinforced masonry walls and interior framing. Diaphragms consist of cast-in-place concrete. Construction consists of metal deck and concrete fill supported on steel framing	1. Unreinforced brick masonry in mud mortar with vertical posts 2. Unreinforced brick masonry in mud mortar 3. Rammed earth construction 4. Adobe block walls 5. Mud walls with horizontal wood elements 6. Massive stone masonry (in lime/cement mortar) 7. Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	Unreinforced Masonry Bearing Walls Low Rise(1-2) Mid Rise(3+)	Rectangular Cut Stone Masonry Block (DS)	Unreinforced, with manufactured stone units	Unreinforced fired brick masonry in cement mortar (BB1)	Unreinforced masonry bearing walls with masonry with wooden slabs (M3.1)/with masonry vaults (M3.2)/with composite steel and masonry slabs (M3.3)/with reinforced concrete slabs (M3.4)
				Rectangular Cut Stone Masonry Block with Mud Mortar, Timber Roof and Floors (DS1		Brick masonry with horizontal reinforcement (BB2)	
				Same as DS1 with Lime Mortar (DS2)		Concrete block (BC1)	
				Same as DS1 with Cement Mortar (DS3)		Stone masonry, squared and cut, dimensioned stone, monumental (BD1)	
				Same as DS2 with Reinforced Concrete Floors and Roof (DS4)			

Table 2.29(k): Comparison of various Building Typologies: Masonry (Non-Engineered)

Masonry	FEMA 310	WHE-EERI	HAZUS	PAGER	EMS98	Coburn & Spence 2002	RISK-UE
Non-Engineered Structures	Diaphragms are stiff relative to the unreinforced masonry walls and interior framing. Diaphragms consist of cast-in-place concrete. Construction consists of metal deck and concrete fill supported on steel framing	1. Unreinforced brick masonry in mud mortar with vertical posts 2. Unreinforced brick masonry in mud mortar 3. Rammed earth construction 4. Adobe block walls 5. Mud walls with horizontal wood elements 6. Massive stone masonry (in lime/cement mortar) 7. Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	Unreinforced Masonry Bearing Walls Low Rise(1-2) Mid Rise(3+)	Unreinforced Fire Brick Masonry (UFB) Unreinforced Brick Masonry in Mud Mortar without Timber Posts (UFB1) Unreinforced Brick Masonry in Mud Mortar with Timber Posts (UFB2) UFB Cement Mortar, Timber Flooring, Timber or Steel Beams and Columns, Tie Courses) (UFB3) UFB3 with Reinforced Concrete Floor and Roof Slabs (UFB4)	Unreinforced, with manufactured stone units	Unreinforced fired brick masonry in cement mortar (BB1) Brick masonry with horizontal reinforcement (BB2) Concrete block (BC1) Stone masonry, squared and cut, dimensioned stone, monumental (BD1)	Unreinforced masonry bearing walls with masonry with wooden slabs (M3.1)/with masonry vaults (M3.2)/with composite steel and masonry slabs (M3.3)/with reinforced concrete slabs (M3.4)

2.4 Discussions

The seismic resistance of a building depends on a large number of parameters such as its geometry, structural system, materials used for construction, quality of construction, etc. For seismic risk assessment it is not feasible to evaluate each and every building in detail. The seismic vulnerability of buildings can be included in risk assessment without undertaking a building-by-building structural assessment if the buildings can be categorised among standard types. The development of a building typology catalogue is thus the first step in comprehensive seismic risk assessment.

In this section, the building types presented in published literature and used in other earthquake-prone countries has been presented. It is seen that most typology classifications are based on a hierarchical listing of attributes. It is further seen that in some countries, the building typology catalogue is very extensive consisting of dozen of building types, while other countries use very few attributes. More extensive building typology catalogue has been proposed in countries where seismic risk assessment is to be carried out at higher resolution, and where the required data is available. In case of non-availability of as-built building data or where the risk assessment is to be carried out at lower resolution, the more approximate building typology catalogue are found adequate.

Chapter 3 Proposed Building Typology Catalogue in Indian Context

In India, country-wide housing database is practically non-existent except for a few data sources that provide limited and generally inconsistent information about housing types or their distribution. It is evident that the future housing data compilations should be based on uniform methodologies and nomenclature that can easily accommodate engineering-based rather than indigenous terms. This is especially important in cases where engineering professionals are not involved in the data compilation. In cases where the data compilation is based on engineering surveys, the definition of structure type should be consistent with standards for the definition of construction types.

Building typologies in various parts of the world were discussed in previous chapter. After evaluating these building typology catalogues and the parameters considered therein, the building typology catalogue for Indian conditions is proposed in this Chapter.

3.1 Parameters for Building Categorisation

Ideally the construction type classification should be based on the knowledge of the structural system, load transfer mechanism, the predominant construction material used, and the performance during past earthquakes. However, most of the raw inventory data did not provide building-specific information and hence it was necessary to adopt broad construction type classification based on material used for the construction of walls and roofs.

For seismic vulnerability assessment of buildings in India, following parameters are considered for building categorization.

3.1.1 Material Type

All the buildings are primarily classified based on the material of construction. There are four material types considered in the study.

1. Masonry and Mortar type
2. Structural Concrete
3. Steel
4. Wooden Structure

3.1.2 Load Resisting System

After the buildings are classified based on their construction material, they are divided based on the type of load resisting system for each material type.

1. Masonry
   i) Wall System (Stone Masonry)
   ii) Wall System (Earthen/Mud/Adobe/Rammed Earth)
   iii) Wall System (Burnt Clay Brick/Block Masonry)

2. Structural Concrete
    i) Moment Resisting Frame
    ii) Shear Walls Structure

3. Steel
    i) Moment Resisting Frame
    ii) Braced Frame
    iii) Light Metal

4. Wooden Structures
    i) Load-Bearing Timber Frame
    ii) Timber Frame with Load-Bearing Masonry Wall

5. Bamboo Constructions
    i) Thatch roof system

Buildings are further divided into sub-types based as explained in Table 3.1.

3.1.3 Height of the Building

Vulnerability of a building to an earthquake changes with the height of the building. Hence, number of stories of the buildings is considered for building classification.

3.1.4 Irregularities

Horizontal irregularities in buildings are given below as defined in Cl.7.1 of IS: 1893 – 2002.

1. Horizontal Irregularities

i) Torsional: If floor diaphragms are rigid in their own plane and maximum storey drift at one end is > 1.2 × average storey drift

ii) Re-entrant corners: If projection beyond re-entrant corner is > 15% of plan dimension in that direction.

iii) Diaphragm discontinuity: if open areas > 50% of gross enclosed area or change in effective diaphragm stiffness from one storey to next > 50%

iv) Out-of-plane offsets: discontinuities in lateral load resisting paths

v) Non-parallel systems

Along with horizontal irregularities, there can be some vertical irregularities which are defined below.

2. Vertical Irregularities

i) Irregularity in load path

ii) Irregularity in Strength and Stiffness

iii) Mass Irregularity

iv) Vertical Geometry Irregularity

3.1.5 Quality of Construction

To consider the local construction practices, quality of the construction in terms of compliance of codes or visual assessment as good or poor is taken into account.

i) Code Complied or Not Complied
ii) Status of maintenance or visual appearance : Good/Poor

3.1.6 Ground Slope

In several parts of the country such as in the Himalayas, along the Eastern and Western Ghats and in North-Eastern states, a large number of constructions are located on hill slopes. When houses are constructed on gentle slopes, the ground is typically levelled before construction. However, if the building is located on a steep slope, it is very likely that different portions of the building have their foundation at different levels. This results in building with vertical members with unequal height and constitutes a very severe case of vertical irregularity. Even if such buildings have their vertical members fully tied with horizontal members or bracing, these buildings are likely to perform much worse compared to similar buildings on level ground when subjected to same base excitation. The information on ground gradient is therefore considered as a basic structural data for classification of buildings from seismic vulnerability considerations.

In the proposed building typology catalogue, this information is recorded as:

i) Level Ground (Slope $\leq 20^o$)
ii) Sloping Ground (Slope $>20^o$)

3.2 Proposed Building Typologies

Bases on the parameters explained earlier in this chapter, buildings are classified into various categories. Proposed building typologies are explained in Table 3.1.

Table 3.1 classifies buildings in various categories. A unique alpha-numeric 12 letters code is assigned to each building typology. Each of the parameter considered has been given a two letter code (Alphabet/Numeric).

Building Category column in Table 3.1 gives a unique 12 letter code for each typology where values of X will be values specified in columns: Number of Stories, Irregularity, Quality of Construction and Ground slope.

Code for the column No. of Stories in Table 3.1 will be same as number of stories in the building under consideration.

Table 3.1: Proposed Building Typologies for Indian Buildings

Material	Sub-Types	Load Resisting System(Lateral /Vertical)	Parameters				Building Category
			No. of Stories	Irregularity	Quality of Constru-ction	Level of Ground	
Masonry (M)	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof) (A)	Stone Masonry Walls (ST)	Number of stories in the building (01-99)	Horizontal Only (HO) or Vertical Only (VO) or Horizontal and Vertical both (HV)	Code complied and Good (CG) Code complied and Poor (CP) or Not code complied and Good (NG) or Not code complied and Poor (NP)	Level Ground (LG) or Sloping Ground (SG)	MASTXXXXXXXX
	Massive stone masonry (in lime/cement mortar) (B)		-do-	-do-	-do-	-do-	MBSTXXXXXXXX
	Dressed stone (regular shape) masonry (in lime/cement mortar) (C)		-do-	-do-	-do-	-do-	MCSTXXXXXXXX
	Mud walls (D)	Earthen/Mud/ Adobe/Rammed Earthen Walls (EW)	-do-	-do-	-do-	-do-	MDEWXXXXXXXX
	Mud walls with horizontal wood elements (E)		-do-	-do-	-do-	-do-	MEEWXXXXXXXX
	Adobe block walls (F)		-do-	-do-	-do-	-do-	MFEWXXXXXXXX
	Rammed earth/Pise construction (G)		-do-	-do-	-do-	-do-	MGEWXXXXXXXX

Table 3.1(a): Proposed Building Typologies for Indian Buildings

Material	Sub-Types	Load Resisting System(Lateral /Vertical)	Parameters				Building Category
			No. of Stories	Irregularity	Quality of Constru-ction	Level of Ground	
Masonry (M)	Unreinforced brick masonry in mud/lime mortar (H)	Burnt clay brick/block masonry walls (BW)	-do-	-do-	-do-	-do-	MHBWXXXXXXXX X
	Unreinforced brick masonry in mud mortar with vertical posts (I)		-do-	-do-	-do-	-do-	MIBWXXXXXXXX
	Unreinforced brick masonry in cement mortar (J)		-do-	-do-	-do-	-do-	MJBWXXXXXXXXX
	Unreinforced brick masonry in cement mortar with reinforced concrete floor/roof slabs (K)		-do-	-do-	-do-	-do-	MKBWXXXXXXXX X
	Unreinforced brick masonry in cement mortar with lintel bands (various floor/roof systems) (L)		-do-	-do-	-do-	-do-	MLBWXXXXXXXXX
	Confined brick/block masonry with concrete posts/tie columns and beams (M)		-do-	-do-	-do-	-do-	MMBWXXXXXXXX X
	Unreinforced lime/cement (various floor/roof) (N)	Concrete block masonry (CB)	-do-	-do-	-do-	-do-	MNCBXXXXXXXXX

Table 3.1(b): Proposed Building Typologies for Indian Buildings

Material	Sub-Types	Load Resisting System(Lateral/ Vertical)	Parameters				Building Category
			No. of Stories	Irregularity	Quality of Constru-ction	Level of Ground	
Masonry (M)	Reinforced, in cement mortar (various floor/roof systems) (O)	Concrete block masonry (CB)	-do-	-do-	-do-	-do-	MOCBXXXXXXXX X
	With reinforced concrete (P)	Mixed Structure (MS)	-do-	-do-	-do-	-do-	MPMSXXXXXXXX
	With composite steel (Q)		-do-	-do-	-do-	-do-	MQMSXXXXXXX X
	With timber, bamboo or others (R)		-do-	-do-	-do-	-do-	MRMSXXXXXXX X
Structural Concrete (C)	Designed for gravity loads only (predating seismic codes i.e. no seismic features) (A)	Moment Resisting Frame (MF)	-do-	-do-	-do-	-do-	CAMFXXXXXXXX
	Designed with seismic features (various ages) (B)		-do-	-do-	-do-	-do-	CBMFXXXXXXXX
	Frame with unreinforce d masonry infill walls (C)		-do-	-do-	-do-	-do-	CCMFXXXXXXXX
	Flat slab structure (D)		-do-	-do-	-do-	-do-	CDMFXXXXXXXX
	Precast frame structure (E)		-do-	-do-	-do-	-do-	CEMFXXXXXXXX
	Frame with concrete shear walls (dual system) (F)		-do-	-do-	-do-	-do-	CFMFXXXXXXXX

Table 3.1(c): Proposed Building Typologies for Indian Buildings

Material	Sub-Types	Load Resisting System(Lateral/ Vertical)	Parameters				Building Category
			No. of Stories	Irregularity	Quality of Constru-ction	Level of Ground	
Structural Concrete (c)	Open ground storey structure (G)	Moment Resisting Frame (MF)	-do-	-do-	-do-	-do-	CGMFXXXXXXX X
	Walls cast in-situ (H)	Shear Wall Structure (SW)	-do-	-do-	-do-	-do-	CHSWXXXXXXX X
	Precast wall panel structure (I)		-do-	-do-	-do-	-do-	CISWXXXXXXXX
	With load bearing masonry (J)	Mixed Structure (MS)	-do-	-do-	-do-	-do-	CJMSXXXXXXXX
	With composite steel (K)		-do-	-do-	-do-	-do-	CKMSXXXXXXX X
	With timber, bamboo or others (L)		-do-	-do-	-do-	-do-	CLMSXXXXXXXX
Steel (S)	With brick masonry partitions (A)	Moment Resisting Frame (MF)	-do-	-do-	-do-	-do-	SAMFXXXXXXXX
	With cast in-situ concrete walls (B)		-do-	-do-	-do-	-do-	SBMFXXXXXXX
	With lightweight partitions (C)		-do-	-do-	-do-	-do-	SCMFXXXXXXX
	With various floor/roof systems (D)	Braced Frame (BF)	-do-	-do-	-do-	-do-	SDBFXXXXXXXX
	Single storey LM frame structure (E)	Light Metal Frame (LF)	-do-	-do-	-do-	-do-	SELFXXXXXXX
	With load-bearing masonry (F)	Mixed Structure (MS)	-do-	-do-	-do-	-do-	SFMSXXXXXXX
	With Reinforced Concrete (G)		-do-	-do-	-do-	-do-	SGMSXXXXXXX

Table 3.1(d): Proposed Building Typologies for Indian Buildings

Material	Sub- Types	Load Resisting System(Lateral/ Vertical)	Parameters				Building Category
			No. of Stories	Irregularity	Quality of Constru-ction	Level of Ground	
Steel (S)	With composite steel and concrete vertical members (H)		-do-	-do-	-do-	-do-	SHMSXXXXXXX
	With Timber, Bamboo or others(I)		-do-	-do-	-do-	-do-	SIMSXXXXXXX
Wooden Structures (W)	Thatch roof (A)	Load Bearing Timber Frame (TF)	-do-	-do-	-do-	-do-	WATFXXXXXXX X
	Post and beam frame (B)		-do-	-do-	-do-	-do-	WBTFXXXXXXX X
	Walls with bamboo/reed mesh and post (Wattle and Daub) (C)		-do-	-do-	-do-	-do-	WCTFXXXXXXX
	Frame with (stone/brick) masonry infill (D)		-do-	-do-	-do-	-do-	WDTFXXXXXXX X
	Frame with plywood/gypsum board sheathing (E)		-do-	-do-	-do-	-do-	WETFXXXXXXX
	Frame with stud walls (F)		-do-	-do-	-do-	-do-	WFTFXXXXXXX X
	Dhajji-Diwari with light weight sloping roof (G)		-do-	-do-	-do-	-do-	WGTFXXXXXXX X
	Dhajji-Diwari with heavy/stone sloping roof (H)		-do-	-do-	-do-	-do-	WHTFXXXXXXX X
	Thatra with timber plank partitions with light weight sloping roof (I)		-do-	-do-	-do-	-do-	WITFXXXXXXX X
	Thatra with timber plank partitions with heavy/stone sloping roof (J)		-do-	-do-	-do-	-do-	WJTFXXXXXXX X

Table 3.1(e): Proposed Building Typologies for Indian Buildings

Material	Sub- Types	Load Resisting System(Lateral /Vertical)	Parameters				Building Category
			No. of Stories	Irregularity	Quality of Constru-ction	Level of Ground	
Wooden Structures (W)	Thatra with Dhajji-Diwari partitions with light weight sloping roof (K)	Load Bearing Timber Frame (TF)		-do-	-do-	-do-	WKTFXXXXXXXX
	Thatra with Dhajji-Diwari partitions with heavy/stone sloping roof (L)		-do-	-do-	-do-	-do-	WLTFXXXXXXXX
	Kath-Kunni walls with stone packing with light weight sloping roof (M)		-do-	-do-	-do-	-do-	WMTFXXXXXXXX
	Kath-Kunni walls with stone packing with heavy/stone sloping roof (N)		-do-	-do-	-do-	-do-	WNTFXXXXXXXX
Bamboo (B)	Thatch roof (A)	Bamboo frames with Bamboo/Ekra/ straw partitions'Bunga' (BF)	-do-	-do-	-do-	-do-	BABFXXXXXXXX

3.3 Discussions

The various parameters considered for building typology catalogue in the Indian context has been presented in this section. The parameters have been presented based on building typology catalogues developed in other countries and also considering the predominant constructions types in India. Further the building typology catalogue has considered the seismic vulnerability of typical construction types in our country.

Chapter 4 Conclusions

Building typologies adopted world-wide for seismic vulnerability are discussed in this study. After evaluating these, the building typology catalogue for Indian conditions is proposed.

Important international models of building typologies for seismic vulnerability have been evaluated for their technical details and relevance to Indian constructions. These models have been used in different parts of the world. It is noted that the initial proposals for building typology were primarily aimed to improve the ability to assess damage intensity following an earthquake. The typology thus consisted of broad classifications based on the material of construction or a combination of material of constriction and the basic structural system. Over time, as tools for seismic risk assessment were developed, the building typologies have been extended to provide useful data for risk assessment.

It is also seen that very few countries have country-specific building typology. Researchers in several other countries have used standard typology available in published literature.

The recent developments in building typology have considered the requirements of more advanced risk assessment methodologies. These typology catalogues therefore require much larger number of parameters. The typology has been defined consistent with the requirement of vulnerability assessment or for specification of vulnerability functions. It is noted that the parameters used in typology catalogue facilitate selection of vulnerability functions from an ensemble of standard functions.

The Typology Catalogue for Indian buildings has been proposed after evaluating the typology catalogues in other parts of the world. In addition, the proposed typology catalogue has also considered the peculiarities of construction practice in India and experiences from past earthquakes. Parameters such as material of construction, load resisting system, number of storeys, horizontal and vertical irregularities, quality of construction, and level of ground are considered for categorization of buildings. It is proposed that buildings can be given unique 12 letters alpha-numeral code following the survey. The survey form and methods are not included in this report and are covered elsewhere. However, it may be mentioned that the survey will cover a much large number of attributes so that in addition to identification of the building type, the survey will also provide useful information regarding exposure and likely consequences of damage due to an earthquake.

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