Seismic Building Codes

Global and Regional Overview

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The author has developed the Ecuadorian Seismic Code in 1976, worked in the reconstruction project following the 1982 Yemen earthquake, supported the reconstruction work following the 2004 tsunami in Sri Lanka, assessed the reconstruction efforts in Indonesia, assessed earthquake damage following the 2005 Kashmir (Pakistan) and 2007 Pisco (Peru) earthquakes, and has worked two years on the Groningen (Netherlands) induced earthquake project.

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Summary

This report is the outcome of a rapid desk study to identify and collate the current state of evidence (in Nepal and other Low-Income Countries) to assess three issues:

a) *The regulation and effectiveness of seismic building codes in achieving the construction of safer and more liveable buildings, and in creating resilience against disasters*.

Building codes are designed to create quality assurance and durability, with the objective to minimise economic loss due to material and structural deterioration, and to provide basic comfort and safety conditions. In earthquake-prone areas, building codes are complemented by seismic codes, specifying the calculation methods and strength values of key structural elements to avoid building collapse during an earthquake. In countries where building and seismic codes have not been implemented (Haiti, Pakistan, China, Nepal), large loss of life and economic set-back has occurred, compared to countries where seismic codes are strictly enforced (Peru, Chile, New Zealand and Japan) and the loss of life has been minimal.[a] Furthermore, the extent of compliance or non-compliance of the seismic codes only becomes evident after a major earthquake event.

b) The types of seismic building code systems used in different countries (ie. the strength requirements for private housing versus public buildings, such as schools, health facilities or industrial buildings), particularly in countries in the Himalayan region that are similar to Nepal with respect to risk and level of income.

Most seismic codes follow the American Concrete Institute (ACI) calculation methods (Nepal follows the Indian codes, which are similar to the ACI method). Earthquake zoning depends on the geographical conditions in the country. Not all low-income countries (LICs) are able to refine these data, thus requiring large safety margins. While there are no differences in building types, there are differences in the interpretation of the importance of building types (the *i* factor).

c) What systems and mechanisms are used to ensure compliance in areas where seismic building codes are in place, and what examples are there of new technologies or innovative approaches to encourage compliance?

While seismic codes are often updated directly after the occurrence of a major earthquake with many casualties, new codes have little or no effect without an outreach or education system designed to create awareness about their content or when there is no enforcement system to strictly monitor their implementation.

In LICs, there is a large economic effort to upgrade the existing building stock in urban and rural areas, thus requiring tailored financing systems. The public administration is easily tempted to approve permits without any on-site building inspection, thus requiring enforcement of on-site building control to avoid corruption. In rural areas, most buildings are constructed without plans or calculations and realised progressively by village craftsmen and self-help methods, thus requiring code versions which are understandable by local craftsmen. Old code versions are as good as new versions for low-rise housing. When building inspectors are unavailable, community inspection methods have to be developed.

Terminology

Behaviour Factor *q*: Factor used in the strength calculation as 1/*q* to reduce the forces obtained from a linear analysis. This factor is low for box-shaped and stiff buildings (masonry and reinforced concrete), and higher for elastic, flexible, space frame, ductile and base-isolated structures.

Damage Limitation (DL), Damage States (DS), Near Collapse (NC) and Immediate Occupancy (IO): Damage Limitation and the five Damage States are those associated with the damage beyond which specified performance requirements are no longer met. The strength calculation of common structures is based on the Near Collapse (NC) damage state. This means that the support structure is greatly damaged, but has not completely collapsed, and typically means an 'economic write-off'. For buildings that need to remain in operation after a maximum earthquake, the Immediate Occupancy (IO) damage state is used. This means that the structure has some damages, but the structural integrity has not been affected. The highest importance factor *'I'* is relevant here.

Importance Factor *i*: Factor used to enhance the factor of safety. Important structures such as schools, hospitals, large meeting rooms and essential services or infrastructure have *i* values of 1.3 or 1.5 to increase strength.

Epicentre: The area at the earth's surface which is immediately above the origin of the earthquake. The diameter of the epicentre area is about twice as large as the distance from the origin (hypocentre) to the epicentre. Outside the epicentre, the vertical vibrations will reduce more than the strength and amplitude of the horizontal vibrations.

Maximum Earthquake: According to tectonic, soil analysis, measurements and statistics, the largest possible Peak Ground Acceleration (PGA*g*) likely to happen in a specific zone within a given period (varying from 50 to 1000 years). This value is used in the calculation of the forces. Per geographic zone (*Z*), this value is estimated and given in the seismic code of a country.

Magnitude: A logarithmic scale of earthquake size based on seismograph records. The magnitude is related to the total energy released by the earthquake. A number of different magnitude scales exist, including Richter and the Moment Magnitude Scale. The magnitude of earthquake does not determine the force on structures; the force is determined by the Peak Ground Acceleration (PGA*g*).

Peak Ground Acceleration (PGA*g*): The value is measured in the gravity acceleration $g = 9.81 m/sec^2$ and is the determining factor for the earthquake movement affecting the foundation. The forces that are applied to the building are directly related to the mass and the elasticity of the construction.

Retrofitting: The process of strengthening existing buildings to make them earthquake resistant.

Unreinforced Masonry (URM): Also called non-reinforced masonry. Masonry from baked bricks, stones or cement blocks, with cement or lime mortar, glue or clay that has no internal or framing reinforcement. Framing reinforcement is commonly done with reinforced concrete. In most seismic countries URM is not permitted to be used in construction when the maximum earthquake in a zone exceeds PGA*g* 0.2 or 0.25.

SECTION 1

Introduction

1.1 Rationale

The two devastating earthquakes in Nepal on 25 April 2015 (Mw 7.8) and 12 May 2015 (Mw 7.3) 2015 caused a death toll of nearly 9000 people and massive economic damage, especially in the rural areas. Although it has been known for >75 years that a large earthquake of this magnitude or greater was inevitable, insufficient measures were taken to protect the population and infrastructure. In 1994 the Nepal government published a seismic code, however, buildings older than 1994 did not comply with this code and thus many of them collapsed.

Given what experts know about tectonic activity in the Himalayan belt from Tajikistan to Chengdu (China), other large earthquakes are bound to happen. Without adherence to seismic codes, this will cause many casualties due to collapsing structures, which raises several important questions. (1) What is the best way to ensure that urban and rural builders will effectively implement the building and seismic codes? and (2) How does legalisation, control and implementation of seismic codes work in other countries?

1.2 Methodology

Although published scientific academic research on the effect of seismic codes is scarce, a lot of so-called grey literature and information can be found, based on educated assessments from professionals in earthquake engineering and journalists who interviewed seismic specialists following major earthquake events. The sole purpose of the seismic code is to calculate and design structures so they do not collapse during a maximum earthquake. When they do collapse, circumstances exist that were outside the design parameters.

Many variables exist between earthquakes and their effect on the built environment. The main variables are indicated in Table 1 below.

Table 1: Earthquake impacts on building strength

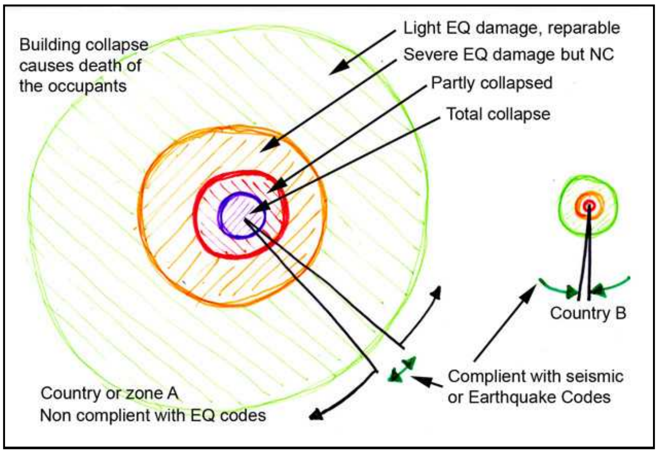
Influence of the EQ Force on Building	Influence on the Building Design	Influences on the Ultimate Construction Strength of Building		
		Design Strength	Execution	Lifetime Durability
Mw or Richter Resulting PGA*g* Distance to epicentre Soil & water conditions Duration & aftershocks Base-isolation	Building mass Elasticity materials Plan regularity Height-stiffness and regularity of building Flexibility joints	Importance factor *i* Behaviour factor *q* Calculation method Calculation margins	Material quality Workmanship Connections Ductility after failure	Maintenance Removal of structural elements (walls) Changing of the load pattern and adding components (stories)
Seismic code Research Statistics Experience	Building code Seismic code Material standards Regulations	Engineering skills Drawing skills Specifications *Inspection*	Plan drawings Descriptions Work supervisor *Inspection*	Building owner Building occupant *Inspection*
	Architect Engineer Planning authority	Engineer, mason (standard design)	Contractor, mason or self-help	Neighbourhood signals problems to *inspection*
Formulated by international and national institutes		Capacity building Skill development	Capacity building Skill development	Local skills and Understanding

Comparing earthquake disasters in terms of collapsed buildings and casualties requires the comparison of these many influences. The comparison of the ultimate construction strength of one collapsed building with a non-collapsed building requires computation of all building designs and execution data, and the actual earthquake load on the foundation, which is an expensive exercise. Most often this data is unavailable in LICs, and certainly not for the collapsed rural houses. It goes without saying that a building that collapsed obviously did not conform to the seismic code.

The above table indicates (in bold) that in addition to the proper implementation of the building and seismic codes, **capacity building** and **inspection** are factors that influence the ultimate building strength. This document provides evidence that in LICs these elements need to be developed and improved upon to minimise future earthquake damage.

An Internet link is provided for all referenced documents for ease of access for further study. Some references from news agencies, giving a summary of interviews with experts, are also included. In addition, some data references have been found through Wikipedia, but data on economic damage and the number of buildings collapsed or damaged depends on the local sources and interpretations. The data, however, give a good general picture of the major differences between countries.

Table 2 in Section 2 provides some public data on casualties and building damage after a variety of large earthquake events. There is a very strong correlation between the number of deaths and the number of collapsed buildings. The seismic codes are designed to avoid collapse of buildings with a maximum earthquake. By avoiding building collapse, human causalities are also avoided. Significant differences appear between countries having applied seismic codes and those without implementation.



The sketch shows the differences between a country A where the seismic code is not adequately implemented (left side), causing large damage including total building collapse, and country B where the seismic code is applied (right side). The number of casualties is related to the building collapse.

The objective of the seismic code is to avoid building collapse. With correct implementation of the seismic code the blue central circle will disappear.

Figure 1: Relation between earthquake damage and seismic code compliance (source: author)

1.3 Contextual Background

Seismic codes are a sub-division of the national building codes, the implementation of which can be divided into immediate-, medium- and long-term activities. Since the implementation of seismic codes will affect all new and existing buildings, the modification of existing codes and standards requires local legislation and extensive capacity building of the controlling and implementing agencies (private, institutional and government). To upgrade the existing building stock to the level of the new (better) codes and standards is a massive undertaking in labour and finances, requiring a thorough analysis of the existing building stock and the development of plans for retrofitting of millions of buildings.

In Nepal with an estimated population of 29 million inhabitants[b] and an estimated family size of 4.5 persons[c], the number of households will be 6.5 million by the end of 2015. The priority buildings listed in the seismic code (public services buildings, schools, etc.) will need to be assessed first. Because the Nepal Building Code (NBC) was only published in 1994 and not made obligatory, over 95% of the existing rural housing and over 90% of urban housing does not comply with the code[1]. On the other hand, many construction companies currently use the so-called framed masonry construction, which has improved seismic resistance.

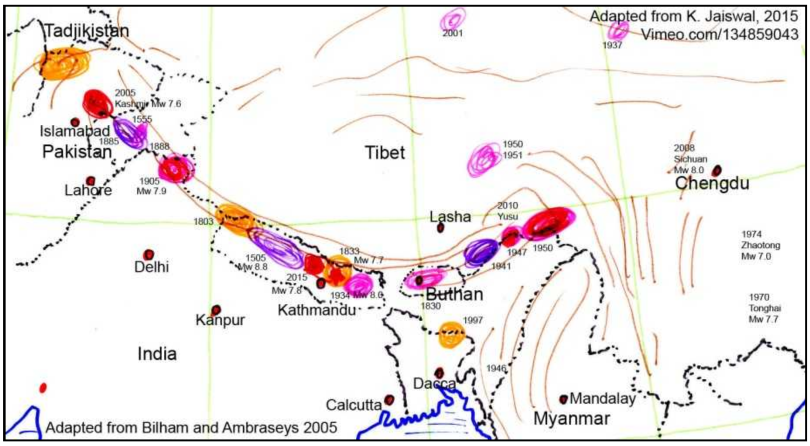


Figure 2: Himalayan earthquake zone (source: adapted from Bilham and Ambraseys 2005[d], and Jaiswal, 2015[e])

While the entire region of Nepal is under the influence of earthquakes, not all seismic zones have the same earthquake magnitudes and hazards due to the various tectonic plate sections, and different population and corresponding housing densities.

The 2005 Kashmir[f] and the 2015 Nepal earthquakes had similar Peak Ground Accelerations (PGA*g* 0.23 and ≈0.25 respectively)[2] at the epicentre but the death count for Nepal was only 1/10th of that of Pakistan. Similar to Nepal, the seismic code was seldom applied in the rural areas, and when applied, only for the new buildings. The difference in casualties between Kashmir and Nepal are due to the following aspects:

- The epicentre in Kashmir was more populated than that of the epicentre in Nepal.
- Kathmandu and the surrounding valley have a very high population density, but were outside the epicentre, resulting in a lower PGAg.3
- In the rural Kashmir district, many reinforced concrete buildings collapsed, whilst in the Nepalese rural area many houses had a lower and lighter masonry construction. Lighter buildings have smaller earthquake loads and lesser foundation problems.
- The Nepal earthquake occurred during a weekend when school children and public servants have a holiday, while in Kashmir the schools were occupied, causing a very high number of schoolchildren to perish in Kashmir.

These points illustrate why earthquakes of about the same magnitude and PGA*g* at the epicentre are not always comparable in the damage caused.

1 These are very rough estimates since no precise data exist. The objective is to indicate that the majority of existing buildings do not comply with the seismic code.

2 The PGA*g* at the epicentre is the most determining factor in the forces that affect constructions during an earthquake. This is measured by the gravity force of 1*g* = 9.81 m/sec^2.

3 During a visit to Nepal in August 2015, the author had a conversation with Mr. Suraya Narayan Shrestha, Deputy Executive Director of the National Society for Earthquake Technology-Nepal (NSET), and his colleague Mr. Bijay Upahyay. They estimated the value in Kathmandu at PGA*g* 0.15-0.18 and PGA*g* 0.25 at the epicentre, based on a single seismograph in the region.

SECTION 2

Comparison of Seismic Codes and their Effect

2.1.1 Effectiveness of Seismic Codes

“Earthquakes Don’t Kill People; Buildings Do” is a very well known quote, used in many reports about earthquake damage and preparedness materials. Building codes in general are designed to provide quality and safety for the building occupants and safeguard their assets and economic investments. Seismic codes are designed to prevent the total collapse of the building during a maximum estimated earthquake event. The general seismic codes need to be complemented with national data about the strength and characteristics of that maximum earthquake event per zone, since the strength of the earthquake will decrease with the distance from the epicentre.[g] The PGA*g*, soil conditions, resistance of the buildings and the number of buildings per region will determine the total economic loss after each event[h]. Table 2 illustrates the differences in damages and costs from earthquakes in countries where the seismic codes were applied and those in which they were not.

In relation to the Kashmir 2005 earthquake, the following observations were made:
“Even though Pakistan has designated seismic zones, the area that suffered in the earthquake was either not classified or was deemed to be Zone 2 (equivalent to Uniform building code UBC Zone 2: low to moderate risk).”

“Seismic hazard is not given a great deal of attention in urban planning and policy decisions, and seismic design does not appear to be high priority, except for major or high profile projects.” [Both quotes are from the Earthquake Engineering Research Institute EERI special report, page 7. (February 2006)]

Interviews from Live Science editor Jeanne Bryner, with seismic specialists on the Sichuan, China earthquake. Article: *Why the China Quake Was So Devastating.* (May 2008).

"You certainly wouldn't see the extent of damage you see here [in China]," said Reginald DesRoches, a professor of civil and environmental engineering at Georgia Tech. "I'm pretty confident about that. You just wouldn't see the level of damage, because they do really enforce the regulations, particularly in California."

"China didn't get an adequate seismic design code until following the big earthquake they had in 1976," DesRoches said. "If the buildings were older and built prior to that [1976 earthquake], chances are they weren't built for adequate [resistance to] earthquake forces."

Particularly the poorer, rural villages in China were hardest hit this week, according to news reports, highlighting a gap in building-code oversight that's related to economics.

"The earthquake occurred in the rural part of China," said Swaminathan Krishnan, assistant professor of civil engineering and geophysics at Caltech. "Presumably, many of the buildings were just built; they were not designed, so to speak."

Krishnan added, "There are very strong building codes in China, which take care of earthquake issues and seismic design issues. But many of these buildings presumably were quite old and probably were not built with any regulations overseeing them."

Brick buildings without steel reinforcements would be considered the most vulnerable to collapse during ground-shaking, Krishnan said. "Now we can confidently say there are no un-reinforced masonry buildings in southern California."

Several points about the importance of building codes have been made by these and other seismic experts:

- With the implementation of seismic codes the level of damage would be far less.
- Buildings that predate the adoption of the codes did not comply with the code.
- In rural areas buildings are not designed by engineers or architects, but rather constructed with local experience.
- Un-reinforced masonry buildings are very vulnerable to earthquakes.
- New buildings do not necessarily comply with all seismic code regulations.

Table 2: Relation between earthquake magnitude, damage and costs

Year of Eearthquake	Country	Mw	Max. PGA*g*	Deaths	Buildings fully Collapsed, Destroyed	Estimated Economic Loss Bn USD$	Loss in % of GDP [i]	Deaths per 1000 Collapsed Buildings (CB)	Year the Code was Published	Evidence of Seismic Code (SC) Applied	Type of Buildings Collapsed: Adobe Blocks	Stone	URM	Old RCC	Further Information BC = Building Code SC = Seismic Code CB = Collapsed Buildings EQ = Earthquake
1995	Kobe, Japan [j+k]	6.9	0.80	6,434	80,000	114	2.3%	80	1950[l]	Yes	-	-	-	?	• No CB conformed with SC. • Most CB dated from before publishing of SC. • High population densities result in more casualties. • A large PGA*g* in epicentre results in a large EQ affected area. • Retrofitting seldom occurs for buildings from before the SC, except Japan and NZ. • In rural areas, SC is usually not applied for new buildings (Pakistan, China, Nepal). • Not following BC or SC due to corruption leads to CB (China, some in Pakistan). • After a large EQ the SC is usually upgraded. • Countries with old SC have better training and implementation of the SC. • Lightweight, symmetric and elastic buildings are less affected by EQ.
2005	Pakistan, Kashmir [m]	7.6	0.23	88,000	? 400,000	5	0.4%	? 220	1986[n]	No	+	+++	+	+++	
2007	Pisco, Peru [o+p+q+r]	8.0	0.49	519	33,000	0.3 [s]	>5%	16	1970[t]	Yes	+++	-	++	+	
2008	Sichuan, China [u+v+w]	7.9	0.23	87,150	? 1000,000	192	?	? 87	1959[x]	No[y]	++	?	+++	++	
2010	Chile [z+aa+bb]	8.8	0.65	525	81,000	30	8-17%	6.5	1972	Yes	++	-	++	+ (50)	
2010	Léogâne, Haiti [cc+dd+ee]	7.0	0.44	222,570	105,000	8-14 [ff]	>120%	2120	n/a	Zero	-	-	++	++++	
2011	Christchurch NZ [gg]	6.3	1.88	185	2	40	≈10%	x	1976[hh]	Yes	-	+	+	2	
2011	Tōhoku, Japan [ii+jj]	9.0	2.99	28,000	100,000	380	3-4%	280	1950k	Yes	-	-	+	+**	
2015	Nepal * [kk+ll+mm+nn]	7.8	≈0.25	8,790	605,253[oo+pp]	6.6	50%	14.5	1994[qq]	No	+	++	++++	+	
2015	Illapel, Chile [rr+ss]	8.3	0.25	15	270	0.1	0.15%	x	1972	Yes	-	-	+	++	

? Data is not adequately verifiable from different sources, which is often the case in LICs

+++ Represents number of buildings collapsed, - being none, + being few, +++ being many

* The ground acceleration in Kathmandu valley was lower than the epicentre and measured at maximum PG*A*g =<0.18. The Nepal earthquake reports possibly had its own definition on what is considered totally collapsed, partly collapsed, destroyed and economically totally lost.

** The Japan Tōhoku PG*A*g was 10 times stronger than that in Pakistan, China or Nepal with greater population density. Combination of type of building and application of the seismic code kept the number of victims relatively low.

2.1.2 Comparison of Earthquake related Casualties

The following observations can be made based on the above table:

- Having a seismic code does not mean that the code is implemented. Often the seismic codes are only implemented for new buildings and in urban areas (as was the case in Pakistan and China).
- In countries where the building codes and the seismic codes are implemented (New Zealand, Chile, Japan), the number of collapsed buildings, and therefore the number of casualties, is low in comparison to countries where the seismic codes have not been implemented (Pakistan, China, Nepal).
- The PGAg differs greatly between earthquake events, making a true comparison difficult and in some cases, not very relevant. With a PGAg = 0.5, twice the earthquake load exists on a building as compared to a PGAg = 0.25 and hence results in far greater damage.
- A high population density at the epicentre increases the number of buildings collapsed.
- Developed (high-income) countries have more capital damage, but the percentage of loss to GDP is smaller than that of LICs.
- Most building collapse is caused from use of non-reinforced building materials such as adobe, stone and baked brick. Reinforced concrete construction (RCC) buildings that are not designed according to seismic and building codes also collapse.

In Pakistan, many old government buildings, including stone and masonry schools, collapsed in the earthquake event.[tt] These buildings predated the building code.

The damage from the 2008 Sichuan earthquake was a result of ignoring the building code, the seismic code, and from not retrofitting old URM buildings. The building code specifies the concrete quality, but contractors left out much of the cement. The concrete quality was so poor that engineers and the press referred to it as "tofu" (bean curd).[uu]

Both the 2010 Chile and 2011 Christchurch[vv] earthquake events demonstrate the small number of casualties when building and seismic codes are properly adhered to.[4] Most deaths in Christchurch were caused by the collapse of the CTV and Pyne buildings, which after a thorough and lengthy investigation were found to be non-compliant with the code.[ww]

Especially in Chile, framed masonry construction for low-rise dwellings as specified in the seismic code is commonly adhered to due to awareness by the people, and through a proper administrative and enforcement system. In addition, good instruction manuals following the code are available for non-supervised self-help builders in villages.[5]

The epicentres of both the Chile and Peru earthquakes were along the coastline, meaning that the total effect on land was about 50% compared to earthquakes occurring on land, such as those in the Himalayan region.

4 Most buildings were compliant to the seismic code, but a thorough and lengthy investigation of the two buildings which collapsed, the CTV and Pyne buildings, were found non-compliant to the code.

5 The Ministerio de Vivienda y Urbanismo of the Chilean Government has published large numbers of technical manuals on housing. See http://www.minvu.cl/opensite_20070402125030.aspx

Figure 3: Map of the 2010 Chile earthquake, showing the epicentre along the coastline

**Map reference: https://en.wikipedia.org/wiki/2010_Chile_earthquake*

The PGA*g* of the earthquake in Chile was much larger than that of the Pakistan and Nepal earthquakes. Although the population density in Chile is larger, the terrain has less slopes and unstable soils than in the Himalayan countries. Furthermore, the damage to buildings is related to their resistance to the earthquakes, which is different for each building type and size. The fragility chart in Figure 4 shows the relation between building types and the possible damage by earthquakes of different strengths.

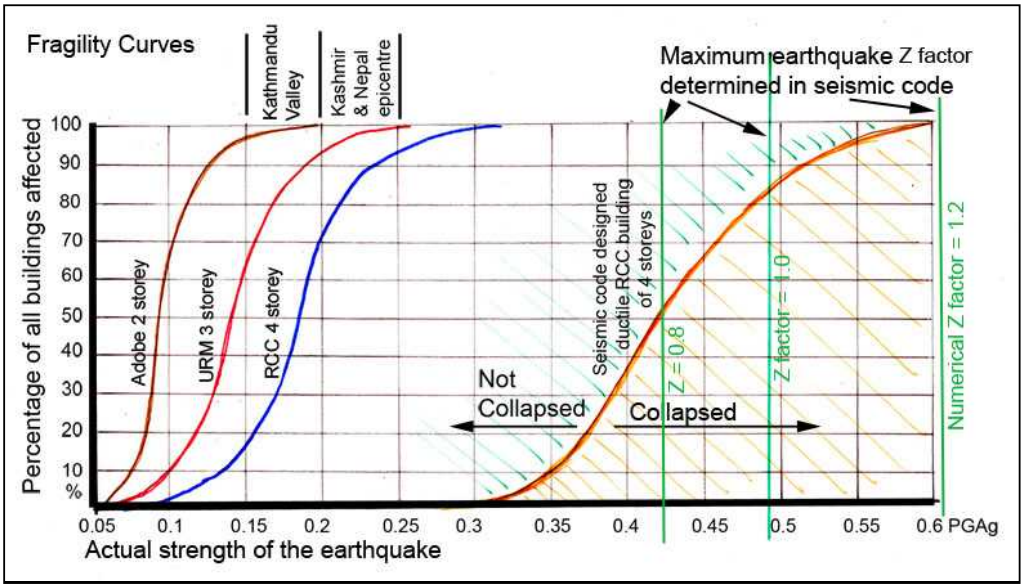


Figure 4: Fragility curves of different building types (Source: author)

The percentage of buildings that partly or totally collapse with a given PGAg is on the right hand side of the curved S line. For each type of building a chart can be made indicating the level of damage. The orange S curve is for buildings that conform to a seismic code with PGAg < 0.5. Each S curve has its own bandwidth due to many construction and site variations.

Figure 4 illustrates why many RCC buildings collapsed in the Kashmir 2005 earthquake, and why many did not collapse in the Kathmandu valley during the 2015 earthquake.

The S curve of the timber houses in Japan, would be on the right hand side of the orange curve of seismic resistant RCC buildings. The PGA*g* of the earthquake that occurred in 2011 in Tōhoku, Japan earthquake lies outside on the right hand side of the above chart.

The 2010 Léogâne Haiti earthquake had a PGA*g* = 0.44, which is a strong earthquake. With the very low quality construction strength, the instant collapse of low-income dwellings was inevitable. The death rate was also very high because of the high population density and the poor quality of the majority of buildings.[xx] In Haiti there is no existing national building code nor do they follow building codes from other countries. This resulted in damage as a percentage of the national GDP (>120%) which reflects the importance of having codes and adhering to them.

The large Chilean earthquakes of 2010 in Concepción (Mw 8.8) and the very recent 16 September 2015 in Illapel (Mw 8.3) show the positive effect of applied seismic codes.yy Illapel, being less densely populated than Concepción, had even fewer casualties. As reported, due to *"…the longstanding enforcement of seismic building codes and improved emergency response"* [quote from reference [p]] fewer buildings collapsed.

From the above, three conclusions can be made:

- When a large number of deaths occurred, codes were not applied (China, Pakistan, and Nepal) or there was no building or seismic code (as in the case of Haiti).
- Unreinforced masonry (URM) in adobe (Peru, 2007) baked brick (China, Nepal) or stone (Pakistan, Nepal) are the most vulnerable building materials.
- Countries with a long-standing seismic code also (often) have improved implementation and enforcement.

Seismic engineers analysing the 2007 Pisco, Chile earthquake commented the following:

Quote from conclusions of: **http://www.iitk.ac.in/nicee/wcee/article/14_01-1076.PDF**
"The 2007, August 15 earthquake may be classified as mild for Lima, and moderate for Pisco and Chincha. This earthquake put into evidence a series of defects that are present in masonry constructions. It is believed that most of the defects are due to the informality in the constructions, although National Construction Codes are available for Seismic and Masonry design (as well as adobe)."

Quote from conclusions of: **http://www.iitk.ac.in/nicee/wcee/article/14_01-1067.PDF**
"In spite of the large number of destroyed houses (58,581) and affected population (200,000), the number of casualties was relatively low (519 deaths). This is due to three main factors: the long duration of the earthquake event with an intermediate portion of low level ground motions that allowed dwellers to escape, the fact that most adobe houses were single storey with light roofs – typical of arid climates –, and the time of the day (18:40, local time), when most people are awake and out of their homes."

About 80% of all traditional adobe structures within the affected area (about 3,000km2) collapsed or were severely damaged. Earth structures designed for earthquake resistance performed satisfactorily. Structures built for earthquake resistant design, such as 1 to 6 storeys RC confined masonry buildings had minimum levels of damage.

Closing Remarks from reference:

https://www.eeri.org/site/images/eeri_newsletter/2010_pdf/Chile10_insert.pdf

"Chile is a country with stable institutions and a prosperous economy that, in response to a history of frequent strong earthquakes, has developed and implemented programs and standards to improve safety and selective infrastructure operability following major earthquakes. Like many other economically developed countries in the world, including the United States, however, Chile is also a nation of income inequality and many marginal structures that are at higher risk to earthquake effects.

The February 27, 2010, earthquake, with its long durations of earthquake ground shaking and ensuing tsunami inundation, demonstrated both the effectiveness and the shortcomings of modern earthquake risk reduction programs. Consequently, the earthquake and its effects are especially relevant and important to seismic risk reduction activities in other earthquake-prone parts of the world."

2.1.3 Comparison of Economic Damages

The economic aspect of adherence to earthquake-resistant building codes is demonstrated by the cost of the damage in relation to the PGA*g* and the population density at the location of the earthquake. Although well-developed and highly populated countries (such as Japan) might have many buildings and infrastructure damaged by a major earthquake, the eventual (high) cost of reparation will represent only a small percent of the country's GDP. The impact of a major earthquake on a nation with a small GDP will, obviously, be comparatively greater.

The type of building construction in the coastal cities of Chile is somewhat comparable to that in the Kathmandu valley, but the economic damage in Chile is much less than the estimated economic loss in Nepal (50% of GDP) since the GDP of Chile is 15 times greater than that of Nepal.

From Table 2 and the above observations, several conclusions can be made:

- In nations with a large GDP the financial loss from earthquake damage is much higher than in countries with a small GDP because the total building stock has a higher capital value.
- In nations with a large GDP, better education and government control/enforcement results in the application of the seismic codes and subsequently less collapsed buildings. The total economic damage from earthquakes in terms of percentage of the national GDP is therefore less than the GDP percentage in LIC countries.

When the earthquake damage is large in relation to the GDP of a country, the resilience capacity of that country will be greatly affected. This is typically the case in countries like Haiti and Nepal. In Haiti, in the absence of a seismic code, the economic damage is 120% of the GDP. This very high percentage is due to the small country size, small GDP and massive amount of damage incurred.

2.1.4 Upgrading or retrofitting building stock that predates seismic codes

The main financial problem lies in upgrading old buildings (ie. those that predate seismic codes) to meet seismic standards, which often requires a far greater percentage of the building value as opposed to adding features to a new construction. In the case of low-rise rural houses, it is usually more cost-efficient to pull down the old building and construct an entirely new building. This, however, requires a major investment for low-income families. External or community-based control on extensions and new buildings would ensure that seismic codes are correctly implemented. In LICs when subsidies are unavailable, income-generating projects, in combination with education and community-based construction control, are potential ways to realise new buildings that adhere to the codes.

Thus for LICs it is very important to comply with seismic codes, as not doing so negatively affects the resilience of the entire population.

2.1.5 In conclusion

The key lies in the application of seismic codes, which will reduce building collapse, subsequently reducing casualties.

So why are seismic codes not applied in a country when they exist?

The answer relates to the following points:

- Existence of easy to comprehend building and seismic codes
- Access to these documents, also in rural areas
- Economic means to follow the codes
- Supervision and enforcement

Comprehension of seismic codes in rural areas, for low-rise dwellings and self-help construction depends greatly on the literacy level of the masons and the availability and accessibility of the codes to the local population. For medium-rise and high-rise buildings, precise calculations are required, which in turn requires relevant training of construction engineers, architects and building craftsmen by local and national institutions. The population has to have a good level of awareness about the need to comply with the codes and a corrupt-free enforcement system is necessary.

Evidence from the World Economic Forum (WEF) report on Public-Private Partnerships (PPPs) in Nepal earthquake response indicated that even where education is sufficient, there is still a conscious decision not to invest in retrofitting to make domestic dwellings stronger.[zz] This is related to the poverty level of the people and their personal priorities.

2.2 Main Types of Seismic Code Systems

The resilience of a country is strongly influenced by the seismic resistance of its infrastructure. For this reason the seismic strength demands for public buildings and infrastructure are higher than for common domestic dwellings occupied by few people. This is achieved in two ways:

- The earthquake load factor is increased for the essential buildings (importance factor i).
- Generally most buildings are calculated for No-Collapse or Near-Collapse (NC), while essential buildings that need to function in the wake of a maximum earthquake event are calculated on the basis of Immediate Occupancy (IO). IO may show some non-structural damage to the building support system, but the building will remain serviceable.

2.2.1 Seismic codes used worldwide

The large population concentrations in the biggest cities require ever higher buildings, which respond differently to earthquakes than low houses. Since the static linear calculations cause over-dimensioning of the strength of tall buildings, newer calculation methods, such as the **time history analysis**, have been introduced.

For low-rise buildings the strength differences between calculation methods are small between the calculation methods and only the **static method** can be used.

Most seismic codes of LICs are based on the oldest American Unified Building Code (UBC) (1927) and the American Concrete Institute ACI-318 (from 1956 and later versions).[6]

South America followed and regularly updated the ACI-318, which at that period were LICs: [aaa]

Table 3: Dates of Seismic Codes Development

Year	Country	Code Development
1956	USA, ACI-318	Regular Updates
1962	India [bbb]	Periodic updates
1970	Peru, E.030	2003, 1997, 1977, 1970
1972	Chile, Nch433. of 2009 Mod	2010, 2003, 1996, 1993
1976	Ecuador, INEN-5	Latest in 2001
1994	Nepal, NBC	Largely following India Code.
1986	Pakistan	2007 following American code

With reference to the recent 2007 Pakistan code, the following quote is made:

"The Seismic Provisions are compatible with the Uniform Building Code 1997 (of USA), the American Concrete Institute ACI 318–05, American Institute of Steel Construction ANSI/AISC 341–05, American Society of Civil Engineers SEI/ASCE 7–05 and ANSI/ASCE 7–93. Revisions to these provisions will be made every five years or as and when deemed necessary, which will allow updating the provisions of this code continually."

The Indian Standards on Earthquake Engineering[ccc] have, since 2002, special sections on liquid retaining tanks, bridges and retaining walls, industrial structures and dams. The code is from 1984 with relative values of seismic zone factors[ddd] and therefore rather old compared to the much newer Pakistan Seismic code or the Eurocode 8. It includes:

- IS: 1893-2002 "Criteria for Earthquake Resistant Design of Structures (Fifth Revision)"
- IS: 13920-1993 "Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces"
- IS: 4326 -1993 "Earthquake Resistant Design and Construction of Buildings-Code of Practice 2nd"
- IS:13828-1993 "Improving Earthquake Resistance of Low Strength Masonry Buildings - Guide"
- IS:13827-1993 "Improving Earthquake Resistance of Earthen Buildings – Guidelines"
- IS:13935-1993 "Repair and Seismic Strengthening of Buildings – Guidelines"

The Nepalese National Building Codes (NBC)[eee], dating from 1994, comprises a set of 23 codes and follow the Indian codes. The seismic code related documents include:

[6] The author co-translated and developed in 1975 the Ecuadorian seismic code on the basis of the ACI-318-71. The Mexican, Venezuelan and Columbia codes have the same ACI-318 standard.

- NBC105 Seismic design of buildings in Nepal.
- NBC108 Site consideration for seismic hazards.
- NBC201 Mandatory rules of thumb reinforced concrete buildings with masonry infill.
- NBC202 Mandatory rules of thumb load bearing masonry.
- NBC203 Guidelines for earthquake-resistant building construction low strength masonry.
- NBC204 Guidelines for earthquake-resistant building construction earthen building.
- NBC205 Mandatory rules of thumb reinforced concrete buildings without masonry infill.

The former Indian seismic code described two methods of calculation: the traditional (static) **Lateral Force Method** and the **Response Spectrum Method**. The newest 2002 version also includes the **Seismic Coefficient Method**.[fff]

The 1994 Nepal NBC describes two methods for calculation: the **Seismic Coefficient Method** (static) and the **Model Response Spectrum Method.**

The new 2007 Pakistan code uses the **Minimum Design Lateral Forces** (static) and the **Dynamic Analysis Procedure** linked to the **Response Spectrum Analysis**. The dynamic analysis procedure includes the **Time History Analyses** (linear and nonlinear). These are similar to both the American codes and the Eurocode 8.

The current Chilean seismic code is based on the ACI-05 (from 2005) and includes material specifications according to Chilean norms and higher load factors as compared to the ACI due to their own earthquake zoning. For small structures up to the height of 20m and structures with high regularity (redundancy) up to 30m, the **static analysis** may be used. For other or larger buildings, the **Spectral Response Methods** are used.[ggg]

2.2.2 Seismic building codes suitable for low-rise and self-built houses

Rural houses in Nepal are commonly built without adherence to seismic codes or guidelines. Kathmandu urban houses that already have four stories are often vertically extended, while the shear walls on the ground floor have been removed to make space for shops. This is done without consideration of the changing load patterns during earthquakes.[7] Even with reinforced concrete, the reinforcement of the concrete or the curing are often inadequate.

The problem of not adhering to building or seismic codes in rural areas is due to:

- The lack of availability of the codes; sometimes high purchase costs are involved.
- The lack of government or institutional supervision on the application of the codes.
- The lack of engineering education of the building industry in the rural areas.
- The high cost of transport and building materials like steel and cement.
- The lack of general earthquake knowledge and fatalistic attitudes towards earthquakes.

For urban areas, this is the same due to:

- Avoidance of obtaining building permits involving engineers or building inspection due to high costs and do-it-yourself activities to keep implementation costs low.
- The lack of an automatic on-site inspection system for all construction activities.
- The possibility of paying off inspectors and getting approval without site inspection.

[7] By removing shear walls in one direction (on the street side facade), the stability of the construction in the length direction along the street is affected. The ground floor has become a “soft storey”.

- The general low level of knowledge about the effect of earthquakes on buildings.

On the other hand, the new seismic codes such as those used in Pakistan, USA and the Eurocode 8, have become so complex to understand that qualified structural engineers require additional high-level training to enable them to realise the calculations.

To overcome these barriers, India, Peru and Nepal (for example) have developed simple code versions for rural housing, which include explanatory illustrations. A good example from Peru is the well-illustrated “**Construction and Maintenance of Masonry Houses for Masons and Craftsme**n” by Marcial Blondet.[hhh] Other examples are from EERI [iii] and Swiss Development Corporation (SDC) [jjj]. These types of documents are more easily understood by the village craftsmen who are hired by house owners wanting to extend their existing houses.

In India, several simple guidelines and instructions have been developed over many years by Prof. Anand S. Arya (for EERI) under the terminology of “**non-engineered constructions**”[kkk], which have culminated in a “Handbook on Seismic Retrofit of Buildings” (April 2007) in association with the Indian Institute of Technology.[lll] In Indonesia simple **non-engineering manuals** were developed by Teddy Boen[mmm] with similar information.

In Nepal, the NBC documents 201, 202 and 205 are the Mandatory Rules of Thumb (MRT) illustrated guidelines, which are voluntarily followed by many village administrations, but not enforced. Lack of enforcement is largely owing to the deteriorating administrative situation since the Maoist uprising in 2000, however, most of the houses that collapsed during the April 2015 earthquake predate that period. A review of the existing housing stock, including the ancient temples, was not undertaken to assess them for the inevitable earthquake event that recently rocked the central districts.

Himalayan countries periodically update their seismic codes, as was done by Pakistan after the devastating Kashmir earthquake in 2005. Other countries obtain new seismic data that allows fine-tuning of the seismic codes (e.g. USA, Japan and Chile). However, the very large and complicated engineering documents are incomprehensible to the general public, building technicians, qualified masons and the poorly educated civil servants who need to enforce these regulations. Moreover, in Nepal and India the compliance with seismic codes is voluntary, not mandatory.[nnn]

2.2.3. Variations in code requirements of public buildings

All building codes apply factors to strengthen structural performance for essential public buildings and services, such as infrastructure, schools, meeting rooms, hospitals, police and fire stations, power supply, communication installations and installations with dangerous materials such as fuel depots. The values of these factors will differ between countries and will be related to the value assigned to the structure and the earthquake zones in which the structure is located.

The ACI and Eurocode 8 not only make a distinction in the importance factor of buildings per category (eg. schools and hospitals), but for the total number of occupants as well (eg. assembly halls). The Eurocode 8 includes multi-storey apartment buildings in the higher importance category because of the large number of occupants per building.

The final design strength of the construction is influenced by other design factors. Whilst the maximum earthquake force that can occur cannot precisely be determined beforehand, neither can the location. Micro-zoning of the maps is only possible with detailed study of the geological situation of the area and seismic performance analysis of the upper 20m of the soil. The definition of the strength multiplier factors is based on risk factors, which can be determined in a different way in each country. The Eurocode 8 has an annex earthquake intensity zoning map per country. There are, however, small variations in strength across borders.[ooo]

Table 4 shows some increased strength seismic requirements for various construction categories. The standard strength value is for common housing, having an importance factor *i* = 1.0, which is a multiplying factor of the earthquake load or in the strength calculations. These values are additional to the multiplier values for the respective seismic zones or soil types.

Table 4: Incremental Strength for Construction Importance

	Importance Factor *i*					
Description of Construction Categories	Chile	Indian 2002	Nepal 1994	Peru ppp	Pakistan 2007+	Euro-code 8
No permanent occupation by people, farms, storage, agricultural buildings with small number of cattle. No danger for loss of human life. CC1a*	0.6					0.8
General housing, low rise ≤ 4 stories. CC1b* Little risk of loss of human life or economic damage.	1.0	1.0		1.0	1.0	1.0
General housing, medium high > 4 stories and public buildings. Schools, hotels, office buildings, churches, halls < 300 persons. CC2* Average risk of loss of human life and substantial social, economic or environmental loss or damage.	1.2	1.5	1.5	1.3	1.0	1.3
High risk of loss of human life and very serious social, economic or environmental loss or damage. CC3* Tribunes, fire fighting and lifesaving facilities and garages for these services, police, hospitals, community halls >300 persons, power stations, masts.	1.2	1.5	1.5	1.5	1.25	1.5
Gas distribution networks and water supply services. Chemical industries and large fuel storages.	1.2		2.0	1.5	1.25	1.5
Monumental structures.		1.5	1.5			
Telephone, TV, radio, subway and railway stations. Important** industrial establishments.	1.2	1.5		1.5	1.25	
VIP residences** and residences of important** emergency persons.		1.5				1.0
Offices, residential quarters for senior personnel required for central and district-level rescue and relief operations.			1.5			
Group housing and nursing homes for the elderly.						1.5

***** The CC refers to the Consequence Category of the Eurocode 8.
** The definition of what is important is inadequately defined. This is specified in the Nepal code.
+ The Pakistan code adds an additional factor of 1.15 for snow load and 1.15 for wind load on essential facilities and buildings that occupy more than 300 persons.

The table above shows existing differences between codes. Chile has a lower importance factor, but higher zoning factor than other codes, resulting in little damage. The Indian codes are the only ones that specify housing of “Very Important People” for a higher safety margin. The Eurocode 8 and the ACI-05 relate strongly to the number of persons that can be assembled in a single building. The Pakistan code also follows the ACI-05 and goes into great detail about all the possible categories of houses and additional factors for snow and wind for the most important structures. Multiplying the lower importance factor of 1.25 with these snow and wind factors of 1.15 brings the multiplier to 1.44.

The conclusion regarding seismic codes worldwide are:

- They follow the same calculation techniques and include simple calculations.
- They are regularly updated with the newest codes from developed countries.
- The calculations depend on the national zoning (micro-zoning based on soil

conditions).
- Countries have slightly different interpretations about the importance factors *i.*

2.3 Seismic Building Codes Need to Be Obligatory and Adhered To

So what are the reasons why the Chilean government has been successful in adopting and enforcing seismic codes while the Nepalese government has not? The reason lies in stability and good governance. While Chile has a stable government with a good education system throughout the country, Nepal, since the 1934 Kathmandu earthquake, has had an intensive political transition with two dynasties resulting in a high turnover rate of Government and therefore low focus on public expenditure, infrastructure and earthquake preparedness. Even when the Nepal Building Codes (NBC) were published in 1994, enforcement was not mandatory. Shortly after the codes were published, the Maoist uprising began and any type of investment in rural areas came to a halt. Moreover, the tremendous influx of rural people into the Kathmandu valley has dramatically increased the volume of seismically unsafe buildings and unplanned settlements.

Another contributing factor may be the capitalistic model of the building industry, in particular the developers.[8] When constructions are developed for the purpose of selling, the legal and technical responsibility of the financing agents and contractors usually finishes after the sale has been made. Without the liability of legal or financial claims following a disaster, there is no incentive for developers to comply with disaster preventive regulations. When the actual building value is linked to the correct execution of the building and seismic codes, and this is properly verified, the financing agencies or the client would demand compliance with the codes. The issue here is: to what extent is the design and execution properly verified, and how can corrupt practices, such as buying off engineers and inspectors, be avoided?[9]

The 25 April 2015 Nepal earthquake resulted in various strong comments and opinions on the quality of the constructions[qqq], the lack of mandatory seismic regulations[rrr] and poor building practices, including not following the available building codes[sss]. This referred document indicates that 95% of the government buildings in the country are not in compliance with the national building code NBC 105. Although the Nepalese Mandatory Rule of Thumb (MRT, series 200) have NBC numbers, implementation is not mandatory.[ttt] The Village Development Committees (VDCs) in Nepal have autonomy whether to adopt these regulations or not. Most VDCs have voluntarily adopted the codes and MRTs, but for new buildings only. For the majority of the rural buildings, there is no legal requirement for seismic upgrading, and enforcement is under the jurisdiction of the local administration.

In addition, the 2009 report "Recommendation for Update of Nepal National Building Code" is also not mandatory and the administrative structure of human capacity or competence is unavailable in the many district headquarters of Nepal. While building inspectors in Nepal may eventually be stationed in the district headquarters (the VDCs), they will require long travel times and incur large expenses to inspect the ongoing building projects in all the small villages (which is not presently happening).

While this is currently the situation in Nepal, the same is true for many other areas in the Himalayan zone where communications are difficult and time consuming. Earthquake construction guidelines should be made easily understandable for the respective user groups. The current Pakistan Building Code 2007 is an excellent document, but not practical

8 Observations from the author; seismic engineer and architect and worked in many countries.

9 Already 1780 B.C., the Law Code of the Persian King of Hammurabi, builders remained responsible for their entire lifetime for the quality of the construction. Mistakes were severely punished. Available at: www.macadams.posc.mu.edu/txt/ah/Assyria/Hammurabi.html discovered in 1901.

for application by villagers, which is significant considering that over 90% of the building volume in the rural areas is carried out by self-help builders and small village contractors.

Based on the above information:

- The codes must be understandable by the local user population (builders/contractors, house owners/principals and inspectors).
- There must be a control system to ensure the codes are correctly implemented. In remote areas, this can be feasible on a community-based structure as central government control would be extremely expensive (manpower, transport, time).

The 2005 Kashmir earthquake is another example to illustrate the importance of adhering to mandatory building codes. The extensive damage resulting from this earthquake has been well documented, the causes of which have been attributed to the following:

(1) Many of the collapsed buildings were constructed prior to the introduction of the 1986 seismic code, and were realised by self-help builders.
(2) Many of the buildings constructed after 1986 did not follow the seismic code. In fact, in the rural areas, engineers and/or the codes were often unavailable.
(3) Good concrete construction was not carried out according to the general building code[10]. The concrete quality of nearly all constructions were substantially below the design value due to poor execution in the application of steel reinforcements, over dimensioning of beams, low quality of the aggregates and poor curing under hot, dry or excessive cold local climatic conditions.[11]
(4) Many buildings collapsed due to foundation failure, mainly because the heavy constructions were built on steep slopes having unstable soils. The country does not have a suitable set of guidelines to clarify what types of buildings can be built on slopes.

This example illustrates that first, good building practices must be followed according to the building code, such as in the control of building materials (aggregates) and workmanship (ie. correct mixing of the concrete components, formwork and curing of the cast material)[12]. Secondly, the seismic code must be followed.

This requires extensive training, on all levels, in relation to:

- Interpretation, application and supervision of general building code requirements.
- Comprehension of earthquake resistance thus the reasons for a recommended design.
- Understanding the financial implications of earthquake damage to one’s property and investment.
- Knowledge on how to modify a standard design to the requirements of the principal.
- Skills to apply the learned methods under local circumstances in the field.

In order to verify the qualification of the engineers, building inspectors and craftsmen, a range of different courses with the obligation to obtain diplomas or certificates should be developed. Each of these certificates should outline the level of competence. With these

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10 Rural people tend to follow the construction methods from bigger towns, as these buildings have more status and are assumed to be more durable. For reinforced concrete, this is only the case when the design follows very specific rules for materials, reinforcement and curing.

11 The same problem appeared to be the case for urban buildings in the China, Sichuan earthquake.

12 When, on a fixed budget, the owner wants more building volume and the size of the building is increased, the quality of the building materials and the execution of the structure will suffer. Once the construction is completed, the deficiencies are virtually invisible and will only appear with an earthquake event, becoming fatal for the building occupants when the building collapses.

certificates, a principal will be able to select construction staff that has the appropriate competencies for the type of work required. At the village level, the relevant professions in each community should control ongoing construction activities rather than depend on external inspectors. This is to the benefit of the inhabitants as it is more sustainable, will build community resilience, and because it is the community who suffers from fatalities, casualties, losses and damages from an earthquake.

2.3.1 Retrofitting, improving the existing building stock

The USA Federal Emergency Management Agency (FEMA) has published a large number of documents on seismic retrofitting, such as:

- *Techniques for the Seismic Rehabilitation of Existing Buildings* (FEMA 547/2006 Edition)
- *Engineering Guidelines for Incremental Seismic Rehabilitation* (FEMA P-420/May 2009)
- *Evaluation of Earthquake Damaged Concrete and Masonry Wall Building – Basic Procedures Manual* (FEMA 306, prepared by Applied Technology Council (ATC-43 Project, 1998)
- *Repair of Earthquake Damaged Concrete and Masonry Wall Buildings* (FEMA 308/1999)

Although these documents are advisories and not mandatory codes, they provide a wealth of information that can be adapted to and adopted in low-income countries.

In India, the IS 13827:1993, *Improving Earthquake Resistance of Earthen Building – Guidelines* and the IS 13828:1993, *Improving Earthquake Resistance of Low Strength Masonry* Buildings – Guidelines and their updates are also advisory documents and not mandatory codes.

Although new seismic codes should be an improvement over former codes, masses of houses were constructed, in both rural and urban areas of Nepal, according to older codes or no codes at all. This also means that in the rural areas the building inspectors and the qualified construction staff need additional training in assessing existing buildings in compliance with the seismic codes.

2.3.2 Abstract relevant sections of seismic codes for user groups

The complete seismic codes provide rather complex calculation methods for a wide variety of buildings and building sizes, with forward and backward referrals and referrals to other codes and standards, with minimal illustrations and no calculation or design examples. An example is the recent Pakistan seismic code, which is over 200 pages. While not all users of the seismic code are required to understand all the details and calculation methods presented, relevant sections for user groups can be extracted to make them more user-friendly. The Nepalese NBC 105 is a good example of a user-friendly version suitable for rural areas and buildings <20m. The Mandatory Rules of Thumb (MRT) are also examples of abstracted seismic building codes. They provide advice on a specific construction size, which if enlarged will not conform to the seismic code.

The Indian Handbook 2007 has a good example in the beginning of providing simple explanations about the seismic-resistant design and includes some practical design and calculation examples. With over 600 pages, however, it is a very large and onerous document for many users. Furthermore, for rural people who do not have access to the Internet, it would be difficult to obtain this information.

From the entire seismic code, those sections relevant to a specific target user group should be abstracted and presented in a smaller document, along with illustrations and useful examples that can be replicated. This would make the seismic code more user-friendly for (proper) implementation. In this respect, the MRTs are a good initial attempt. For self-help builders in rural areas, the seismic codes relating to construction of low-rise buildings (e.g. <10 m high) can be abstracted. The content should include practical information about slopes, foundations, structural systems with materials used, connections between walls and floors and the location of openings, all required for typical seismic designs.

Since many buildings are similar, standard design drawings can be provided for a variety of structures. When these design drawings are followed, and the material quality according to the specifications is used, the building will comply with the code. The abstracts should indicate to what extent variations in the design can be realised while retaining the code specifications. For example, the net cross-section of the ground floor walls at window level should have a minimum value or a column can be made shorter, but not longer.

Figure 5 depicts a typical zoning map from the Nepal NBC 105 document[uuu] (this example is, Figure 8.2. from the document), more specifically it is seismic zoning factor Z. The zoning factor Z is a multiplier in the formula for the calculation of the earthquake load on the building.

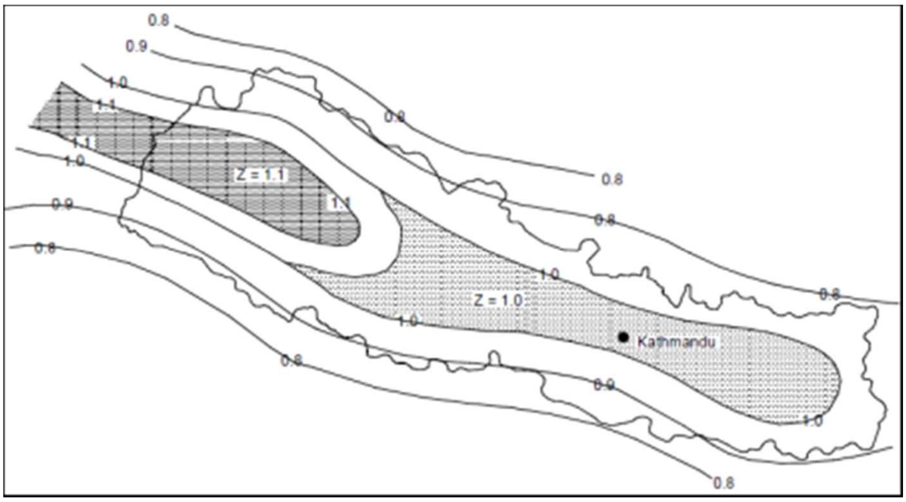

Figure 5: Earthquake Zones in Nepal (adapted from Figure 8.2 in Nepal National Building Code, NBC 105: 1994, Seismic Design of Buildings in Nepal)

The map shows that Kathmandu lies in zone 1.0. Micro-zoning is influenced by deep geographic conditions and soil types.

The required building strength depends, among other factors, on the seismic zoning factor Z, the importance factor of the building. The strength calculation depends on the building response, which is related to the height of the building and the construction method. The existing guidelines and MRT give examples of constructions, but do not adequately specify the height of the constructions.

The seismic codes provide different calculation methods. These calculation methods are suitable for low-rise, mid-rise and high-rise buildings, which all have a different building response related to their height and construction material. Applying rather precise calculation methods, with a large error margin in the zoning factor and an even larger fluctuation in the construction quality on-site, is not very useful in the rural areas where the local professionals do not have the skills to apply these refined calculations

In mountainous areas, the definition of the building height can be interpreted widely due to construction on slopes (see image below). Definition differences between the building height and the number of habitable floors are not given in most seismic codes.

The indication of the maximum number of four habitable floors (stories) for housing is only provided in *The Netherlands Basis for Design*, which is attached to the Eurocode 8. All low-rise buildings (< 10m or four habitable floors) are calculated with the simplest **linear static method**. The Eurocode 8 makes a distinction between buildings which are <20 m and >20 m.

In the Himalayas, where there are both low and high mountain areas, large climatic differences exist, resulting in different building design requirements. When for high altitudes and low altitudes the same seismic zoning Z (see map of Nepal above) exists, it means that the same seismic strengthening will be required for different architectural building designs and different construction materials. The available guidelines and MRTs do not give sufficiently detailed designs applicable to the different climatic zones.

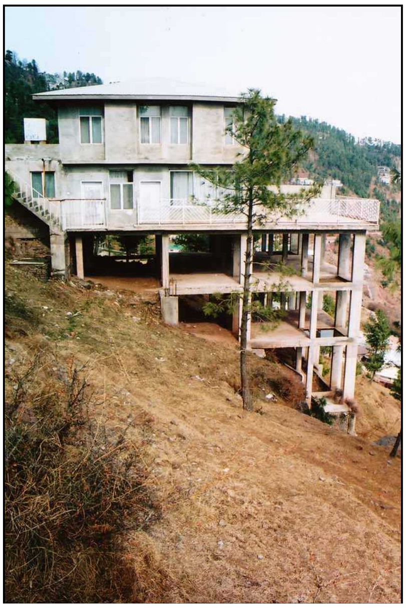

Photo by author, Pakistan 2005

SECTION 3

Resilience of the Society

3.1 Resilience of the Society and the Economy

The resulting damage of an earthquake to a country's infrastructure, building stock and percentage of GDP will affect the ability of its society as a whole to recover. If people understand the origin of earthquakes, effects and methods to strengthen their houses, they will be more motivated to undertake action than when they have a fatalistic attitude. When people have the skills and material resources, they can start reconstruction immediately, provided there is sufficient finance available. On the other hand, if the competency level of the public administration is poor, recovery will be negatively affected.

A country's infrastructure includes the communication system, road network, health services, water supply and sanitation. When building and seismic codes are not applied, the adequacy of infrastructure to withstand earthquakes may be compromised and thereby affect the resilience of communities following the earthquake event. The high costs of repairing the failed infrastructures will place an additional economic burden on a low-income country.[vvv]

The Eurocode 8 and the Pakistan codes provide specifications for several types of infrastructure, but not all LICs have these additional specifications.

During the 20th century, the monarchy in Nepal invested little in the country's infrastructure. From 2000 to 2008 Nepal suffered from political instability due to the Maoist uprising, abolition of the monarchy and change of government. To date, there has been little development related to the seismic code for infrastructure.[www] Legislative decision-making, which is necessary to implement codes and educational systems, has, for various reasons, been hampered by a divided government, and has therefore not been a priority issue for the government.

Improving resilience to disasters requires decisive action on many levels:

- Capacity building of the government administration at all levels, but especially in relation to the seismic code requirements, on-site supervision and enforcement.
- Awareness-raising[xxx] of the population on matters relating to earthquake-resistant building techniques, preventive measurements, and the fact that many multi-storey buildings need structural retrofitting. This point applies also to the following paragraph.

The resilience of the villagers in the aftermath of an earthquake disaster will greatly depend on their livelihood and income generation capacity, as they have to rebuild their dwellings themselves. As much as 90% of the private housing stock in the rural areas is self-built with local masons and contractors in a progressive manner, collecting materials and adding regularly a building section when finances are available.

Rural and urban households need to raise finances for local craftsmen to build the houses with them, or pay off loans.[13] As the ability to pay off loans is generally very low, means to stimulate and facilitate income-generation include:[14]

- Redevelopment of sustainable earthquake-resistant local infrastructure. This includes water and sanitation, communication and road access, which are all essential in the event of a disaster.
- Development of a local finance structures that support local income-generating activities.
- Participation in the maintenance of road infrastructure, securing access to and the transport of building materials, and communication with district centres.
- Local development and production of lightweight and elastic building materials (such as timber and bamboo) and thermal insulation options. Thermal insulation materials are highly relevant for the higher altitudes in the Himalayan region from Tajikistan to Chengdu.

3.2 Improving Resilience through Inclusions in the Seismic Code

To improve the resilience of a country in the aftermath of an earthquake, the seismic codes need to be specific to infrastructure, particularly when related to mountain areas. The document "*Earthquake Protection 2nd Edition*" indicates that collapsing buildings causes 80% of deaths.[yyy] In order for the building and seismic codes to be effective in safeguarding the resilience of the society, it is insufficient to only look at the houses, schools and office constructions. The codes need to cover all infrastructure, including roads, dikes, bridges, water storage, dams (hydro-electric), power cable support masts, and other critical infrastructure.

Modern seismic codes, such as the Eurocode 8 Part 1[zzz], Japanese[aaaa] and American[bbbb] codes include such infrastructure and their annexes. The Japanese building code was revised after the 2011 Tōhoku earthquake[cccc], becoming one of the most advanced codes in the world. Pakistan also reviewed its building code in the wake of the 2005 Kashmir earthquake and released a revised version in 2007 (Seismic Provisions-2007).[dddd] In addition, Pakistan law specified the Regulation for Engineering Education.[eeee]

The Eurocode 8 has specific sections on bridges (Part 2), retrofitting (Part 3), tanks and silo's (Part 4), foundations (Part 5) and towers and masts (Part 6).

For mountainous countries such as in the Himalayan, hazards can be related to village planning, roads, hydro-electric dams, retention walls and building on slopes. Although codes may give guidelines for the construction of infrastructure, these will be subject to general hazard mitigation measures. Since the country and village planning is subject to the local geography, it would be difficult to define exact measurements for hazard mitigation in seismic codes.

The International Centre for Integrated Mountain Development (ICIMOD) developed an extensive report on glacial lake outburst floods (GLOF)[ffff], outlining the potential risks associated with glacial lakes and GLOF. Bursting of hydro-electric dams and GLOF are specific problems for mountainous countries, and these need to be considered in local planning. The possibility of large landslides that can block entire river valleys (as happened

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13 It is unlikely that national and international donor organizations will largely finance the rebuilding of private housing on the same level as happened after the 2004 tsunami (13 Bn$).

14 This is the opinion of the author, based on experience. No evidence is presented here to support these points.

in Pakistan in 2005) also need to be considered in village planning and the construction of infrastructure.

SECTION 4

Development Options

4.1 From Information to Awareness to Training and Organisation

Training on building or seismic codes is obviously not feasible without these codes being available. Ample material is, however, available on the general principles of earthquake engineering, as well as for low-income housing, such as the new Indian Handbook 2007. The National Society for Earthquake Technology (NSET) in Nepal has been involved for many years in earthquake awareness training for the general public and training of masons and other professional staff.[gggg]

There are four steps required:

(1) Information about the subject.
(2) Awareness of the possibility that you can change your situation and the need to do something about it.
(3) Motivation to want to undertake an action – certification, finances, materials, etc.
(4) The action itself – organization, legalization, etc.

The box below presents information on a Holistic Approach for Safer Non-Engineered Buildings. This has been extracted from *Earthquake and Non-Engineered Buildings Role of Governments, Experts and Guidelines* (Anand Swarup Arya, 2008)[hhhh]

Holistic Approach for Safer Non-Engineered Buildings

In any country undertaking the objective of achieving earthquake safe non-engineered building construction, it must develop a holistic approach consisting of the following action points:

1. *Assessment of the earthquake hazard in the country, which could be expressed in either a probabilistic hazard map or an earthquake intensity-wise map defining the various seismic zones in the country.*

2. *Collection of data on building types existing in the country as well as the kind of non-engineered building construction is prevalent in various geographical areas of the country.*

3. *Assessment of the vulnerability of the identified building types in relation to the various earthquake Intensities. It should lead to categorization of the damageability under future earthquakes.*

4. *Assessment of risk of damage under the postulated earthquake Intensity occurrences, which should also include the awareness of the various communities about the dangers and their preparedness, if any.*

5. *Awareness of various stakeholders, for example, schools, hospitals, industries, resident welfare associations, etc. The awareness issue of safer construction technology will be the most important issue since most losses under earthquakes*

occur due to the collapse of buildings.

6. *Sensitisation of the policy makers and top administrators towards priority actions required and funding to be provided for taking such actions. They need to be made aware of the following actions on priority:*

    - *Creation of necessary legislative instruments for proper town planning as well as rural area habitation development.*
    - *Land-use Zoning for developing Master Plans taking care of hazard proneness of the areas such as landslide and liquefaction potential affected by earthquake activity.*
    - *Development Control Regulations and appropriate Building Bylaws in the Municipal bodies called Urban Local Bodies as well as Rural-Local Bodies called Panchayats in India.*
    - *Training of professionals including architects, engineers, construction supervisors, masons, bar benders and carpenters. In this regard it is to be understood that most non-engineered buildings are constructed in the informal sector without any involvement of architects or engineers, wherein the construction planning is carried out by Master Mason so as to meet the requirements of the owner.*

In all these issues the experts as well as the government have to play extremely important roles.

4.2 Available, Accessible, Understandable and Affordable

Correct information is essential. It must be available, accessible, understandable and affordable.[15] While internationally a variety of information is available, it needs to become more accessible to local target user groups. Accessibility can be improved through the use of the internet and delivery services to the rural areas. Furthermore, the information needs to be tailored to the understanding of the local target groups and the cost of obtaining the right information must be within local users' economic means.

In developing these materials, it is advised to source information, guidelines and training materials from other countries and adapt these materials to the local architecture, social circumstances, cultural elements and language.

This can be done in the following way: [19]

A. Abstracting (not changing) the sections of the seismic codes relevant to low-rise and buildings and tailored to the local architecture. These code abstracts need to be elaborated with calculation and design examples.
B. The building and seismic codes need to be supported with building inspection protocols, including reporting and registration systems and archives. An example is the simple calculation and verification format for the minimum wall section at ground floor window level used in Peru.[iiii]
C. Standard building designs with technical and material specifications for a variety of typologies and climatic zones, allowing minimal design modifications.
D. The development of detailed construction manuals for construction of new buildings focusing on both the building code and seismic code.

15 These principles can be found in a multitude of documents on education and training.

E. The development of manuals for retrofitting and strengthening techniques for existing buildings,[16] such as those developed in Bhutan. The retrofitting manuals should be made available for the different building designs and climatic zoning.

F. Development of specific guidelines and instructions for community-based assessments[17] of environmental hazards, such as landslides, rock fall, flooding, GLOF, soft building soils, the construction of dams and retention walls, road construction, bridges, etc. Because soil stability is a very important issue in mountainous areas, specific guidelines on these issues are urgently required.

The availability of and access to these manuals and designs without cost is important for the low-income population. Download, copy facilities and delivery mechanism to supply these designs at district and rural level would greatly benefit local communities.

The role of experts in achieving building safety was outlined in *Earthquake and Non-Engineered Buildings Role of Governments, Experts and Guidelines* (Anand Swarup Arya, 2008)[iiii]. The following points indicate that guidelines and workable bylaws are essential elements.

The Role of Experts

In achieving safety of various types of buildings in general and non-engineered buildings in particular the most important expertise is required in the field of civil engineering. The experts will have to contribute in the following ways:

- Identification of building types and assessment of their damageability under various earthquake Intensities.

- Carry out research and development studies to determine the available strength of the various building types prevalent in the country, to identify their deficiencies and weaknesses from seismic behaviour point of view, and to work out how such deficiencies and weaknesses can be eliminated or minimized by feasible and economic actions in the field. The objective of such intervention would be to reduce the risk of total collapse and prevent the loss of life as well as loss of contents in future earthquake occurrences.

- The experts should produce such Guidelines which could be easily understood by the construction workers, masons, carpenters and bar benders for adoption in the new constructions.

- The expert's role in developing workable building bylaws cannot be over emphasized. The building bylaws will have to be made in such a way that they are fully transparent, and will make the involved persons accountable for the safety of the buildings.

The professionals should make the results of R & D and the know-how created, available to the community at large without any copyrights or reservations.

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16 In several developed countries like the USA, Japan and New Zealand, the methodology for assessing the existing building stock has been developed. The Federal Emergency Management Agency (FEMA) has an extensive National Earthquake Hazards Reduction Program (NEHRP), which is used in many countries as a guideline for developing their national training. www.fema.gov

The government of Bhutan has adopted the *Post-earthquake Safety Evaluation of Buildings*, *Bhutan Edition* (ATC-20- Bhutan). This ATC-20 instrument is for the assessment of existing buildings.

17 The Aga Khan Development Network (AKDN) in Pakistan has developed between 2000 and 2005 this community based assessment and village hazard mapping in the Northern Areas.

4.3 Approach to Building Codes

The government administrative system is the primary mechanism to ensure compliance. For the purpose of comparison of different administrative systems and approaches used to develop codes, Table 5 outlines the various approaches used by the Asian Pacific Economic Council (APEC) member countries, which rely on three fundamental approaches to developing, adopting, administering and enforcing building codes. [kkkk]

Table 5: Different Approaches to Model Code Development

Approach	Details
Model Code Developed Separate from Building Regulations. Australia, Canada, and USA also follow this system.	This approach utilizes model codes developed and administered by private organizations and quasi-governmental agencies. Jurisdictions have independent responsibility for developing and adopting building codes, and model codes offer an efficient way of doing so. The jurisdictions also manage building code enforcement, including inspection and permit issuance. In such a system, code enforcement officials, building sector professionals affected by the codes, academics and others participate in code development. Model codes are updated every three to five years. Reference standards are developed by separate organizations.
Model Code Developed Alongside Building Regulations by the Government.	A national regulatory system is the most common among APEC economies, with variations coming in the degree of freedom regional (local) governments have in modifying, adopting, and enforcing regulations. In China and Indonesia, the central government develops regulations and codes and local governments may freely adopt or reject the codes and regulations. In Chile, Chinese Taipei, Japan, Korea, Peru, and Vietnam, local governments have little to no authority to modify codes and regulations.
Regulations Specify Use of Best Practices and Standards But Allow Equivalents.	Under this approach, building regulations are developed and enforced by the government. This approach is utilized in Brunei Darussalam, Hong Kong, China, and Singapore. The regulations allow the use of nonlocal codes, standards, and best practices in place of local ones. In Malaysia, local jurisdictions may develop and enforce their own standards.

Note: This table was extracted from APEC Building codes, Standards and Regulations (Table 1B) from August 2013.

The middle system in the above table, where the central government develops the codes, but has currently no authority over the local government bodies (VDC's), is the model followed in Nepal. As mentioned previously, the VDCs, voluntarily follow (or not) the National Code.

The regulatory framework and the roles of the public/private sector of some of the APEC countries are indicated in Table 6 below.

Table 6: The Regulatory Framework and Roles of Public and Private Institutions in Various Countries

	Country	Table 1B: Structural	Table 4: Regulatory framework. Development and Enforcement	Table 4: Regulatory framework. Roles of Public/Private sector
1	Chile	F.2.3 Technical Drawing - Project presentations - Technical Specifications	Through the General Law of Urban Planning and Construction. Administered and Enforced by the Ministry of Housing and Urban Development, and Local level. Directions of Municipal Works.	The Ministry of Housing and Urban Development approves technical standard developed by the National Institute of Standardization, and the regulation of potable water, sewerage and paving installation. It can also prepare technical standards.
2	Japan	Building Standards Law (in mandatory Building Code)	Minister of Land, Infrastructure, and Transport develops and enforce laws. Ordinances of municipal governments are required to conform with the central government laws. Laws are enforced by municipal governments.	Ministry of Land, Infrastructure and Transport (through building and infrastructure control department) develops and administers codes, Quasigovernment standards agencies AIJ and JCI rely on the private sector to develop standards.
3	New Zealand	Building Code of NZ (mandatory)	Building and Housing Department maintains and administers NZ national building code. Code closely follows the Building Act. Building Control Authority (BCA) accredits and registers enforcers of building codes. Enforcers can either be a building control department of a municipal government or a private company appointed by the same. Code is enforced by local government. The building control department and personnel enforcing the code has to be accredited by BCA.	Central government is to develop the Act, and the Building and Housing Department converts it into code. New Zealand Standards are administered by a quasigovernment org. Also relies heavily on standards from Australia and Britain. Private sector is heavily involved in the standards development and updating.
4	Peru	Title III.2 of RNE E.010 (wood), E.020 (loads), E.030 (seismic), E.040 (glass), E.050 (soil, foundation), E.060 (RCC), E.070 (masonry) E.080 (adobe), E.090 (steel)	The Ministry of Housing and Sanitation is responsible for code administration, which is enforced through municipalities. Municipalities enforce code.	Government is involved throughout code development and enforcement. Private sector contributes to development through standards development committees (voluntary or mandatory).

Note: Countries 1-4 in this table were extracted from APEC Building codes, Standards and Regulations. (August 2013).

Although the development of codes and the implementation systems vary in each country, the implementation of the building and seismic codes work. This is owing to several other important aspects:

- Awareness of the need of a national code system and subsequent application.
- Adequate training of all professionals involved from design to construction.
- A stable government structure, which guarantees minimal corruption in extending the building permits according to the seismic code and adequate site supervision.

For the purpose of comparison, Table 7 has been developed to illustrate how the public and private sectors in Nepal, Pakistan and India (non-APEC countries) develop, implement, and enforce the implementation of building codes.

Table 7: The Regulatory Framework and Roles of Public and Private Institutions in Nepal, Pakistan and India

	Country	Structural Codes and Seismic Codes	Regulatory framework. Development and Enforcement	Regulatory framework. Roles of Public/Private sector
5	Nepal	not mandatory NBC105 seismic NBC108 site, NBC201 MRT Rcc masonry infill NBC202 MRT load bearing masonry NBC203 masonry NBC204 earth NBC205 MRT RCC	NBC Development Project (UNDP/UNCHS/ (Habitat)Nep/88/054) from1992 and the Department of Urban Development and Building Construction (DUDBC) assists the Government of Nepal. Voluntarily followed by Village Development Committees (VDCs). Poor enforcement in the Capital, none in rural areas outside VDCs.	The National Society for Earthquake Technology - Nepal (NSET) is part of the private sector of engineers and experts. NSET underlines the importance of both “bottom-up” and “top-down” approaches.
6	Pakistan	NBC, mandatory Conform UBC-1997 (of USA), the ACI 318–05, the ANSI/AISC 341–05, the SEI/ASCE 7–05 and ANSI/ASCE 7–93.	NESPAK did the major part of seismic zoning and completed peak ground acceleration maps for final draft of building code.[llll] There was negligible code enforcement in the earthquake affected area, except for some high profile projects.	No direct information found, but many proposals and ideas on this issue by a team of international experts participating in the ERRA conference 19-22 April 2010 [mmmm] Proposed role of public sector is training and enforcement.
7	India	IS:1893-2002 structures IS:13920-1993 seismic IS:4326 -1993 masonry IS:13827-1993 earth IS:13935-1993 repair	A National Disaster Management Act was adopted by the Indian Parliament in 2005 which have provided the establishment of National Disaster Management Authority at the Centre, the State Disaster Management Authorities in the States, as well as, the District Disaster Management Authorities in all Districts numbering more than 600.	Model Amendment to existing Acts and Building Byelaws in various levels of Local Bodies has been worked out at the Centre and being disseminated to States for implementation.

4.4 Action points

In 2007, the United Nations Centre for Regional Development (UNCRD) initiated a Housing Earthquake Safety Initiative (HESI) in Algeria, Indonesia, Nepal and Peru. The goal of the HESI project was to improve the structural safety of houses to prevent damage and safeguard people's lives, property and livelihood from earthquakes through effective implementation of building safety regulations. Based on this project, four activities (System evaluation, Awareness-raising, Policy development, and Capacity development) were undertaken/were highlighted as key elements. In addition, the HESI training pyramid includes *Management Training, Capacity Building of Technical Person in Implementing Agencies, Capable Designers/Trainers, Contractors Training, Masons Training,* training of *the general public through Orientation Programmes, and House Owner Orientation.*

The objectives of HESI are as follows:

- To raise awareness on the importance of implementing building safety regulation effectively to reduce risk of life and property losses caused by earthquakes
- To develop policy recommendations on improving the safety of houses, particularly that of traditional houses
- To develop capacity of national and local government officials to implement building safety regulations effectively

Based on the assessment in this report, a number of action points can be derived. Also in the reference document: UNCRD, (2008) *FROM CODE TO PRACTICE* the action points are mentioned as part of the Housing Earthquake Safety Initiative (HESI):[18]

The reference document "**Pakistan 8th October Earthquake"** [nnnn] pages 9 and 10, gives also elements related to:

Awareness, decentralisation, capacity building of professionals and government officials, public/private involvement, develop and enforce simple building codes and guidelines for rural and peri-urban areas, safe building practices and earthquake resistant design, and vigilance on proper building execution.

[18] Page 69 of the reference document.

SECTION 5

List of references

[a] CBC News (2 April 2014). *Chile Earthquake: How loss of life, damage was minimized*. Available at: http://www.cbc.ca/news/chile-earthquake-how-loss-of-life-damage-was-minimized-1.2595662 [Accessed 20 October 2015]

[b] World Populations Prospects. Global demographic estimates and projects by the United Nations. Available at: http://worldpopulationreview.com/countries/nepal-population/ [Accessed 20 October 2015]

[c] Statistical Year Book of Nepal 2013. Central Bureau of Statistics. Page 3. Available at: http://cbs.gov.np/publications/statisticalyearbook_2013 [Accessed 27 October 2015]

[d] Roger Bilham and Nicholas Ambraseys (2005) Apparent Himalayan slip deficit from summation of seismic moments for Himalayan Earthquakes, 1500-2000, Current Science, Vol.88, No. 10, pp.1658 – 1163. Available at http://www.iisc.ernet.in/~currsci/may252005/1658.pdf

[e] Kishor Jaiswal (2015) Nepal Earthquakes and Aftershocks. Seismicity and Ground Motions, EERI LFE Briefing for the April 25, 2015 Nepal Earthquake and Aftershocks. Available at: http://www.eqclearinghouse.org/2015-04-25-nepal/files/2015/07/03-Seismology-and-Ground-Motions-Jaiswal-EERI-2015-Nepal-EQ-Briefing.pdf

[f] Dr. A. Naeem et al. (2005) *A Summary Report on Muzaffarabad Earthquake, Pakistan*. Available at: http://reliefweb.int/report/pakistan/pakistan-summary-report-muzaffarabad-earthquake [Accessed 20 October 2015]

[g] A. A. Skarlatoudise et al (2003) *Empirical Peak Ground-Motion Predictive Relations for Shallow Earthquakes in Greece.* Bulletin of the Seismological Society of America, Vol. 93, No. 6, pp. 2591–2603. Available at: http://geophysics.geo.auth.gr/~askar/papers/3.2.2.pdf [Accessed 13 November 2015]

[h] Multiple sources. https://en.wikipedia.org/wiki/List_of_disasters_by_cost. This list are estimated costs. The % of the earthquake damage of GDP is not indicated. [Accessed 20 October 2015]

[i] USGS. (2011 – 1116) Rapid Estimation of the Economic Consequences of Global Earthquakes. Available at: http://pubs.usgs.gov/of/2011/1116/downloads/OF11-1116_508.pdf [Accessed 10 November 2015]

[j] Peter Drysdale. (14 March 2011) Japan's earthquake and its economic impact. EASTASIAFORUM www.eastasiaforum.org/2011/03/14/japans-earthquake-and-its-economic-impact/ [Accessed 20 October 2015]

[k] www.brittannica.com/event/Kobe-earthquake-of-1995 second paragraph for data. [Accessed10 November 2015]

[l] Masayoshi Nakashima et al. (2003) *A Partial View of Japanese Post-Kobe Seismic Design and Construction Practices*. Available at: http://www.ctsee.org.tw/%E5%87%BA%E7%89%88%E5%93%81/200310/ee0401-01.pdf [Accessed on 14 November 2015]

[m] EERI Special Earthquake Report (February 2006). *The Kashmir Earthquake of October 8, 2005: Impacts in Pakistan*. www.ndma.gov.pk/new/aboutus/Earthquake2005.pdf [Accessed 20 October 2015]

[n] Business Recorder (2015) Building a Building Code Available at: http://epaper.brecorder.com/m/2015/11/06/2-page/539790-news.html [Accessed 14 November 2015]

[o] A. San Bartolome and D. Quiun (2008). *Seismic Behaviour of Masonry Constructions in 2007 Pisco, Peru Earthquake*. 14 WCEE, Beijing, China. Available at: www.iitk.ac.in/nicee/wcee/article/14_01-1076.PDF [Accessed 4 November 2015]

[p] J.E. Alarcón, F. Taucer and E. So. (2008) *14 WCEE. The 15 August 2007 Pisco, Peru Earthquake Post-earthquake Field Survey.* Available at: http://www.iitk.ac.in/nicee/wcee/article/14_01-1067.PDF

[q] [q] EERI Special Earthquake Report (October 2007). *The Pisco, Peru, Earthquake of August 15, 2007:* https://www.eeri.org/lfe/pdf/peru_pisco_eeri_preliminary_reconnaissance.pdf [Accessed 20 October 2015]

[r] Water and Sanitation Programme. *Economic Impact of the 2007 earthquake in the water and sanitation sector in four provinces of Peru.* (May 2011). Available at: https://www.wsp.org/sites/wsp.org/files/publications/WSP-LAC-Economic-Impact-Earthquake-Full-Study.pdf Quote: "96% of the Direct Cost Could have been saved" by prevention. [Accessed 11 November 2015]

[s] Klara Neiger, (2013) Impact of Earthquake in Peru's Fross Domestic Product. Available at: http://www.akimoo.com/2013/impact-of-earthquake-in-perus-gross-domestic-product/ [Accessed 10 November 2015]

[t] J.Chavez, O. Khemici, M. Khater & P. Keshishian (2012) *Building Codes and Relative Seismic Vulnerability in Latin American Countries* Available at: http://www.iitk.ac.in/nicee/wcee/article/WCEE2012_4534.pdf [Accessed 12 December 2015]

[u] BBC NEWS science & environment (9 May 2013) *Sichuan 2008: A disaster on an immense scale.* www.bbc.com/news/science-environment-22398684 Sichuan earthquake. [Accessed 20 October 2015]

[v] Encyclopaedia Britannica. John P. Rafferty. *Sichuan earthquake of 2008.* Available at: www.britannica/event/Sichuan-earthquake-of-2008 [Accessed 10 November 2015]

[w] EERI. Special Earthquake Report (October 2008) *The Wenchuan, Sichuan Province, China, Earthquake of May 12, 2008.* Available at: https://www.eeri.org/site/images/eeri_newsletter/2008_pdf/Wenchuan_China_Recon_Rpt.pdf [Accessed 22 October 2015]

[x] Yuxian HU (August 2004) *DEVELOPMENT OF EARTHQUAKE ENGINEERING IN CHINA* . 13 WCEE. Available at: http://www.iitk.ac.in/nicee/wcee/article/13_5008.pdf [Accessed 14 November 2015]

[y] Livescience. Jeanne Bryner Editor. Why the China Quake Was So Devastating. (May 2008) at: www.livescience.com/2527-china-quake-devastating.html [Accessed 10 November 2015]

[z] https://en.wikipedia.org/wiki/2010_Chile_earthquake With the PGA*g* = 0,65 at Conception. Information in box under map. Other sources indicate PGA*g* =0.4. [Accessed 20 October 2015]

[aa] Richard Hinrichs et al. U.S. Department of the Interior, U.S. Geological Survey. USGS, American Red Cross (2011). *Report on the 2010 Chilean Earthquake and tsunami Response.* Open-File Report 2011-1053 v1.1 https://pubs.usgs.gov/of/2011/1053/of2001-1053.pdf [Accessed 20 October 2015] and http://pubs.er.usgs.gov/publication/70045121 [Accessed 10 November 2015]

[bb] EERI Special Earthquake Report (June 2010) *The Mw 8.8 Chile Earthquake of February 27, 2010*

Available at: https://www.eeri.org/site/images/eeri_newsletter/2010_pdf/Chile10_insert.pdf [Accessed 20 October 2015]

[cc] BBC NEWS science & environment (9 May 2013) *Sichuan 2008: A disaster on an immense scale document link to Haiti.* www.bbc.com/news/science-environment-22398684 [Accessed 20 October 2015]

[dd] https://en.wikipedia.org/wiki/2010_Haiti_earthquake Information in box under map. Later sources indicate maximum PGA*g* = 0.44 in town. [Accessed 20 October 2015]

[ee] DEC. *Haiti Earthquake Facts and Figures.* Available at: http://www.dec.org.uk/article/haiti-earthquake-facts-and-figures [Accessed 10 November 2015]

[ff] IDB Inter American Development Bank (16 February 2010) Webstories. *Haiti reconstruction cost may near $14 billion IDB study shows.* www.iadb.org/en/news/webstories/2010-02-16/haiti-earthquake-reconstruction-could-hit-14-billion-idb,6528.html [Accessed 20 October 2015]

[gg] NEW ZEALAND PARLIAMENT, Parliament support, Research papers. (December 2011) Economic effects of the Canterbury earthquakes. www.parliament.nz/en-nz/parl-support/research-papers/00PlibCIP051/economic-effects-of-the-canterbury-earthquakes with new figure of 3-4% for Japan 2011 earthquake. [Accessed 20 October 2015]

[hh] Brian Mitchell (OECD 2004) *Chapter 7 Making Schools Safer: The New Zealand Experience.* Available at: http://www.oecd.org/edu/innovation-education/33629159.pdf [Accessed 14 November 2015]

[ii] Many authors. https://en.wikipedia.org/wiki/2011_Tohoku_earthquake_and_tsunami and further link. [Accessed 20 and 21 October 2015]

[jj] Earthquake report.com. By Armand Vervaeck and James Daniell *Japan Tohoku Earthquake and Tsunami CATDAT 41 Report* Available at: http://earthquake-report.com/2011/10/02/japan-tohoku-earthquake-and-tsunami-catdat-41-report-october-2-2011/ [Accessed 22 October 2015]

[kk] QUARTZ India (22 May 2015) shocking. *The economic damage from the Nepal earthquake is almost half of the country's GDP*. qz.com/409484/the-economic-damage-from-the-nepal-earthquake-is-almost-half-of-the-countrys-gdp/ [Accessed 21 October 2015]

[ll] Sabina S. Surana. *Post-Earthquake Building Safety Evaluations in Kathmandu Valley* (June 2015) Available at: http://eqclearinghouse.org/wp-content/uploads/2015/07/Nepal_Earthquake_Building_Safety_Evaluation_Report_surana.pdf [Accessed 10 November 2015]

[mm] AON Benfield, *2015 Nepal Earthquake Event Recap Report* (2015) Available at: http://thoughtleadership.aonbenfield.com/Documents/201509-nepal-earthquake.pdf [Accessed 10 November 2015]

[nn] Nepal Earthquake 2015: *PDNA, Post Disaster Needs Assessment, Vol. A, Key Findings.* Available at: http://icnr2015.mof.gov.np/uploaded//PDNA%20Volume%20A%20Final.pdf [Accessed 20 October 2015]

[oo] BCOM. The Bolton Council of Mosques. (2007-2015) *The Boxing Day Tsunami – Facts and Figures – Scale of devastation*. www.thebcom.org/ourwork/reliefwork/96-the-boxing-day-tsunami-facts-and-figures.html?start=1 [Accessed 21 October 2015]

[pp] CEDIM, (12 May 2015) Nepal Earthquakes – Report Situation Report No. 3 16:00 GMT https://www.cedim.de/download/CEDIM_impactSummary_EarthquakeNepal2015_Report3.pdf [Accessed 21 October 2015]

[qq] Babar Mahal, *Seismic design of buildings in Nepal* (1994) Accessible at: http://www.scribd.com/doc/6509845/NBC105-Seismic-Design-of-Buildings-in-Nepal#scribd [Accessed 02 December 2015]

[rr] Miami Herald Americas. (17 September 2015) *Engineers vs. God: Chiles building codes take edge off massive earthquake* www.miamiherald.com/news/nation-world/world/americas/article35576640.html [Accessed 21 October 2015]

[ss] EERI ILLAPEL, CHILE CLEARING HOUSE. Curator. (5 Oct. 2015) Dams and Levees. *The state of Dams and Levees following the M8.3 Illapel, Chile earthquake*. www.eqclearinghouse.org/2015-09-16-chile/2015/10/05/the-state-of-dams-and-levees-following-the-m8-3-illapel-chile-earthquake/ [Accessed 21 October 2015]

[tt] Mashable web report. (18 September 2015) *6 Powerful pieces from Ai Weiwei exhibit in London."Straight" (2008-12)* reinforcement bars from collapsed schools from the Sichuan earthquake. www.mashable.com/2015/09/18/ai-weiwei-london/#8vPidTokNPq8 [Accessed 22 October 2015]

[uu] Chi-yuk, Choi. (2013) South China Morning Post. *The shame of Sichuan's tofu schools*. Available at: http://www.scmp.com/news/china/article/1230807/shame-sichuans-tofu-schools [Accessed 22 October 2015]

[vv] Canterbury Earthquake Recovery Authority (CERA). (2012) *Report into CTV building collapse released.* Available at: http://cera.govt.nz/news/2012/report-into-ctv-building-collapse-released-9-february-2012 [Accessed 27 October 2015]

[ww] Canterbury Earthquakes Royal Commission. (2012) *Final Report Volume 6 Canterbury Television Building (CTV)*. Available at: http://canterbury.royalcommission.govt.nz/Final-Report-Volume-Six-Contents ISBN: 978-0-478-39558-7 (Final Report web-quality PDF) [Accessed 4 November 2015]

[xx] INSIDE DISASTER. The Haiti Earthquake. *Why was the Destruction So Severe?* Becacier Guy (6 September 2010) and Jim Pettijohn (21 November 2011). http://insidedisaster.com/haiti/the-quake/why-was-the-destruction-so-severe [Accessed 22 Oct. 2015]

[yy] https://en.wikipedia.org/wiki/2015_Illapel_earthquake [Accessed 20, 21 and 22 October 2015]

[zz] World Economic Forum. (October 2015) *Building Resilience in Nepal through Public-Private Partnerships*. Available at: http://www3.weforum.org/docs/GAC15_Building_Resilience_in_Nepal_report_1510.pdf [Accessed 27 October 2015]

[aaa] J. Chavez, et all (2012). *Building Codes and Relative Seismic Vulnerability in Latin American Countries* 15 WCEE Lisboa 2012. www.iitk.ac.in/nicee/wcee/article/WCEE2012_4534.pdf [Accessed 21 October 2015]

[bbb] NPTEL E-learning courses from the IITs & IISc. P. Anbazhagan (2005?). www.nptel.ac.in/courses/105101004/4 [Accessed 22 October 2015]
and
www.nptel.ac.in/courses/105108076/module4/lecture10.pdf [Accessed 21 October 2015]

[ccc] Bureau of Indian Standards (2015). Indian Standards on Earthquake Engineering, IS 1893:1984 Criteria for Earthquake Resistant Design of Structures. Other Codes on website. http://www.bis.org.in/other/quake.htm [Accessed 21 October 2015]
and
https://archive.org/details/gov.law.is.1893.1984 [Accessed 21 October 2015]

[ddd] Sudir.K. Jain (November 2003) *Review of Indian Seismic Code, IS 1893 (part 1): 2002.* The Indian Concrete Journal. www.iitk.ac.in/nicee/skj/Research_Papers/Review-IndianSeismicCodeIS1893(Part1)2002.pdf [Accessed 21 October 2015]

[eee] Government of Nepal, Ministry of Urban Development. (2015) *NBC # 000 till 208 Codes and Guidelines.* DUDBC, Department of Urban Development and Building Construction. http://www.dudbc.gov.np/buildingcode [Accessed 21 October 2015]

[fff] S. Farrukh Anwar, A. K. Asthana. (June 2013) *Evaluation of Seismic design Forces of Indian Building Code*. International Journal of Engineering Research and Technology. www.ijert.org/view-pdf/3906/evaluation-of-seismic-design-forces-of-indian-builing-code [Accessed 21 October 2015]

[ggg] NEHRP Consultants Joint Venture. (October 2012) *Comparison of U.S. and Chilean Building Code Requirements and Seismic Design Practice 1985–2010.* NIST, Department of Commerce. www.nehrp.gov/pdf/nistgcr12-917-18.pdf [Accessed 21 October 2015]

[hhh] Marcial Blondet. (2005) *Construction and Maintenance of Masonry Houses*. Pontifica Universidad Catolica del Peru. PUCP, SENCICO-Peru and Earthquake Engineering Research Institute, EERI. http://www.world-housing.net/tutotials/confined-masonry-tutorials [Accessed 22 October 2015]

[iii] Roberto Meli & Svetlana Brzev. (August 2011) *Seismic Design Guide For Low-Rise Confined Masonry Buildings.* Confined Masonry Network EERI & IAEE. http://www.world-housing.net/wp-content/uploads/2011/08/ConfinedMasonryDesignGuide82011.pdf [Accessed 22 October 2015]

[jjj] Swiss Agency for Development and Cooperation, SDC (2015) *Guidebook for Building Earthquake-Resistant Houses in Confined Masonry* SDC. http://confinedmasonry.org/wp-content/uploads/2015/09/Guide_CCR_EN-A5-XS.pdf [Accessed 22 October 2015]

[kkk] Anand S. Arya (2000) *NON-ENGINEERED CONSTRUCTION IN DEVELOPING COUNTRIES – AN APPROACH TOWARD EARTHQUAKE RISK PREDUCTION.* 12 WCEE 2000. www.iitk.ac.in/nicee/wcee/article/2824.pdf [Accessed 22 October 2015]

[lll] Central Public Works Department & Indian Building Congress (2007). *HANDBOOK ON SEISMIC RETROFIT (April 2007) Draft for Comments.* www.cpwd.gov.in/units/finaldrafthandbook_apr2007.pdf [Accessed 22 October 2015]

[mmm] Teddy Boen. (December 2001) *Earthquake Resistant Design of Non-Engineered Buildings In Indonesia.* Presented during EQTAP Workshop IV [Accessed 22 October 2015] http://www.buildingtrustinternational.org/Indonesian%20Earthquake%20Resistant%20Design.pdf

[nnn] DownToEarth, DTE staff (27 April 2015). *CSE points out lapses in building regulations in India.* DownToEarth India. http://www.downtoearth.org.in/news/cse-points-out-lapses-in-building-regulations-in-india-49566 [Accessed 22 October 2015]

[ooo] G. Solomos, A. Pinto and S. Dimova. (2008) *A Review of the Seismic Hazard Zonation in National Building Codes in the Context of Eurocode 8*. JRC European Commission (EUR 23563 EN – 2008).

[ppp] *National Building Code, Technical Standard of Building E.030, Earthquake-Resistant Design*. SENCICO. Available at: http://iisee.kenken.go.jp/net/seismic_design_code/peru/NTE-030-PERU.pdf [Accessed 4 November 2015]

[qqq] UNDP Nepal. (14 August 2015). *Construction companies pledge strict adherence to building code.* UNDP's Comprehensive Disaster Risk Management Programme (CDRMP). http://www.np.undp.org/content/nepal/en/home/presscenter/articles/2015/08/14/construction-companies-pledge-strict-adherence-to-building-code-.html [Accessed 22 October 2015]

[rrr] Peter Fabris. (7 May 2015) *Widespread damage from Nepal earthquake due to poor implementation of building code.* BUILDING DESIGN + CONSTRUCTION MAGAZINE. http://www.bdcnetwork.com/widespread-damage-nepal-earthquake-due-poor-implementation-building-code [Accessed 22 October 2015]

[sss] Sangeet Sangrula. (18 July 2013) *Government offices violating national building codes*. Republica Newspaper. http://www.housingnepal.com/news/national/govt-offices-violating-national-building-code [Accessed 22 October 2015]

[ttt] Ministry of Urban Development. (2007) *The Building Act, 2055* www.lawcommission.gov.np www.moud.gov.np/acts-regulations/building-act-2055-1998-english.pdf to be accessed by entering the following words in the search: government, Nepal, building act, regulation 2005 1998. [Accessed 22 October 2015]

[uuu] Government of Nepal, Nepal National Building Code, NBC 105:1994, Seismic Design of Buildings in Nepal, Government of Nepal, Ministry of Physical Planning and Works, Department of Urban Development and Building Construction, Kathmandu, Nepal. http://www.dudbc.gov.np/uploads/default/files/c25f315ba97fe50b056e7803296704b5.pdf

[vvv] WSP-World Bank (May 2011) *Economic Impact of the 2007 Earthquake on the Drinking Water and Sanitation Sector In Four Provinces of Peru.* [Accessed on 14 November 2015] Available at: https://www.wsp.org/sites/wsp.org/files/publications/WSP-LAC-Economic-Impact-Earthquake-Full-Study.pdf

[www] https://enwikipedia.org/wiki/Politics_of_Nepal some statements and data need verification, but the general impression has been expressed in newspapers and was confirmed to the author during his mission in August 2015 in Nepal, Kathmandu, Gorkha and Dhading districts. [Accessed 22 Oct. 2015]

[xxx] The 2015 Earthquake in Nepal. (May 2015) See 3rd (NEPALI) video *EARTHQUAKE PREVENTION DOCUMENTARY*: www.2015earthquakenepal.com/?page_id=97 [Accessed 21 October 2015]

[yyy] Andrew Coburn and Robert Spence, (2002) *Earthquake Protection, second edition.* England, John Wiley & Sons. http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0470849231.html

[zzz] P.Bisch, E.Carvalho et all. (10-11 Feb. 2011) Lisbon. *JRC Scientific and Technical Reports. Eurocode 8: Seismic Design of Buildings, Worked Examples.* eurocodes.jrc.ec.europa.eu/doc/WS_335/report/EC8_Seismic_Design_of_Buildings-Worked_examples.pdf [Accessed 21 October 2015]
and
The European Union, Edict of Government. EN 1998-1 Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings. https://law.resource.org/pub/eu/eurocode/en.1998.1.2004.pdf [Accessed 20, 21 and 22 Oct. 2015]

[aaaa] Hisahiro HIRAISHI et all. (2000) *PERFORMANCE-BASED BUILDING CODE OF JAPAN -FRAMEWORK OF SEISMIC AND STRUCTURAL PROVISIONS*. 12WCEE, New Zealand. www.iitk.ac.in/nicee/wcee/article/2293.pdf [Accessed 21 October 2015]

[bbbb] *FEMA Building Codes*. Official website of the Department of Homeland Security. www.fema.gov/building-codes and further linkages. [Accessed 21 October 2015]

[cccc] Financial Times. James Simms. Japan's authorities move to impose tougher building standards. (26 April 2015). http://www.ft.com/intl/cms/s/0/664099e8-ccc9-11e4-b5a5-00144feab7de.html [Accessed 21 October 2015]

[dddd] Government of Pakistan. Expert Committee and Core Group. (2007) *Building Code of Pakistan, Seismic Provisions 2007.* Ministry of Housing & Works. [Accessed 21 October 2015] www.urbanunit.gov.pk/PublicationDocs/Other%20Publications/Building%20Codes_2007.pdf

[eeee] Pakistan Engineering Council. (2007). http://www.pec.org.pk/buildingcode.aspx with link to code and legal context. [Accessed 21 October 2015]

[ffff] ICIMOD, GFDRR, World Bank et al. ICIMOD (2011) *Glacial lakes and glacial lake outburst*

floods in Nepal. Kathmandu: ICIMOD. ISBN 978 92 9115 194 3 (electronic), LCCN 2011-312004 www.icimod.org/dvds/201104_GLOF/reports/final_report.pdf [Accessed 20 October 2015]

[gggg] PreventionWeb. NSET publication list. National Society of Earthquake Technology (NSET). www.preventionweb.net/organizations/591 [Accessed 22 October 2015]

[hhhh] UNCRD, (2008) *FROM CODE TO PRACTICE. Challenges for Building Code Implementation And the Further Direction of Housing Earthquake Safety* [Accessed on 12 Nov.2015] Available at: http://www.preventionweb.net/files/10591_HESITokyoPapers.pdf

[iiii] *Simplified Evaluation Method Based on Wall Ratio*. Thematic International Workshop 2007. Available at: www.kenken.go.jp/english/information/information/event/ws2007/2-8.pdf [Accessed 04 November 2015],
and
Seismic Design Guide for Low-Rise Confined Masonry Buildings, (August 2011) EERI & IAEE. At: www.world-housing.net/wp-content/uploads/2011/08/ConfinedMasonryDesignGuide82011.pdf [Accessed 04 November 2015].

[jjjj] UNCRD, (2008) *FROM CODE TO PRACTICE. Challenges for Building Code Implementation And the Further Direction of Housing Earthquake Safety* Available at: http://www.preventionweb.net/files/10591_HESITokyoPapers.pdf [Accessed 12 Nov.2015]

[kkkk] APEC *Building codes, Standards and Regulations.* (August 2013) [Acc. 12-11-2015] Available at: http://www3.cec.org/islandora-gb/islandora/object/islandora:1213/datastream/OBJ-EN/view

[llll] M. Haseeb et al (March 2011) *Construction of Earthquake Resistant Buildings and Infrastructure Implementing Seismic Design and Building Code in Northern Pakistan 2005 Earthquake Affected Area.* Available at: http://ijbssnet.com/journals/Vol._2_No._4;_March_2011/20.pdf [Accessed 14 November 2015]

[mmmm] Report of Proceedings. *ERRA INTERNATIONAL CONFERENCE,* (19-21 April 2010) Available at: http://www.erra.pk/Reports/Publications/EIC2010.pdf [Accessed on 14 November 2015]

[nnnn] UNISDR, *Pakistan 8th October Earthquake* (2005) Available at: http://www.unisdr.org/2005/task-force/tf-meetigns/12th-TF-mtg/item2-Pakistan-IATF-12.ppt [Accessed 12 November 2015]

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