Seismic Building Codes in the Himalaya Region

Questions & Answers Related to the 2015 Nepal Earthquake

Photo by the Author after the 25 April 2015 earthquake in Kathmandu.
Not adhering to seismic building codes can lead to building collapse during a maximum earthquake event.

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Date: May 2016
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ABSTRACT

Questions and answers related to seismic building codes in the context of countries in the Himalaya region, such as Pakistan and Nepal. Where do these earthquakes occur? What is the purpose of the seismic code and the relation with the building code? What are the differences between seismic codes of other countries? What variables exist in a seismic code? What technical and/or administrative measurements need to be taken to make the code effective? How does this information translate to a country as Nepal?

The damage caused by the 12 April and 25 May 2015 earthquakes in Nepal is very large in comparison to the Gross National Product. The number of casualties have reached 9000, but is far less than the 80,000 lives lost by the 2005 Kashmir earthquake in Pakistan. The magnitude of these earthquakes was almost similar, so why the big difference in the number of casualties? An important conclusion is that the level of damage and number of casualties is related to the effectiveness of the implementation of the building codes, the seismic codes, geography and population density. Adhering to seismic codes avoids building collapse and hence less fatalities as a result. However, constructing according to the seismic code may still imply substantial damage with a maximum earthquake.

After a large earthquake event, codes are often upgraded, but usually only new high-rise buildings are constructed according to the latest seismic code. The older existing building stock, however, also needs to be upgraded according to the revised seismic code. In countries where many fatalities occur due to large earthquakes, this upgrading of existing buildings had not been realized. For low-rise buildings, the code revisions have no or little effect in the design strength as compared to the older seismic codes. For high-rise buildings, however, the latest methods of seismic design and calculations are more relevant, as they define more precisely the required building strength. Recommendations are made on how to improve the application of the codes, especially for remote mountain areas.

Key Words: Seismic building codes, Himalaya, economy, casualties, retrofit, earthquake, Nepal, Pakistan, unreinforced masonry, framed masonry, reinforced concrete, Chile, Japan.

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The author worked with the INEN (Instituto Nacional Ecuatoriano de Normalización) and investigated a 1975 earthquake in Esmeraldas, Ecuador. That investigation revealed a wide range of problems from errors in the design, structure, execution sequence, corruption with plan approval and building permits, lack of supervision and shortcuts by the contractor in material use. As a result he co-translated with the INEN in 1976 the Ecuadorian seismic code on the basis of the ACI-318-‘71.

As architect and construction engineer, the author worked in the reconstruction project following the 1982 Yemen earthquake, supported the reconstruction work following the 2004 tsunami in Sri Lanka, assessed the tsunami/earthquake reconstruction efforts in Indonesia in 2006, assessed earthquake damage following the 2005 Kashmir (Pakistan) and 2007 Pisco (Peru) earthquakes, and visited Christchurch (New Zealand) in 2012. He assisted in a project formulation for Gorkha after the 2015 earthquake in Nepal and has worked two years on the Groningen (Netherlands) induced earthquake project until October 2015.

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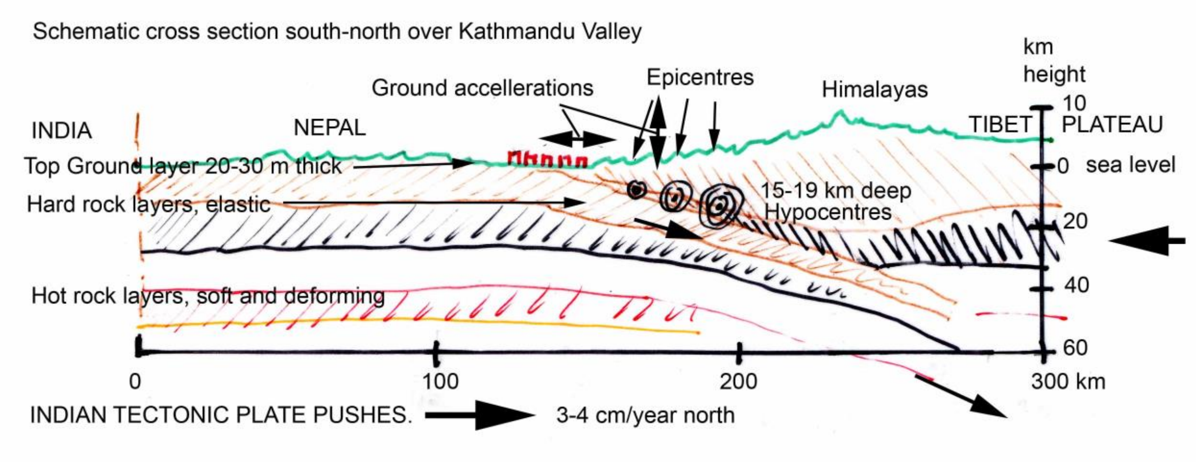

The difference between the Hypocentre and Epicentre are indicated here.
The ground accelerations, vertically and horizontally, diminish with an increasing distance away from the epicentre.

Introduction

In the year after the devastating earthquakes of 2015 in Nepal, several persons have asked me for some clarifications about the earthquake risks and the seismic building code. Generally, people have little knowledge about the technicalities of building and seismic codes. This paper tries to explain the main issues in a not-too-complicated way. In many earthquake countries, many of them being Low-Income Countries (LICs), large number of housing and other buildings were constructed on the basis of traditional architectural knowledge. The new, higher buildings are increasingly vulnerable to earthquakes, particularly in the recently urbanised areas in the Himalayas.

Systematic earthquake engineering was only introduced after large earthquakes caused many fatalities, such as in Portugal (1755), Italy (1911) and Japan (1923)[a], in combination with the realisation of taller buildings. Most seismic codes of LICs are based on the oldest American Unified Building Code (UBC – 1927)[1] and the calculation methods of the American Concrete Institute (ACI-318 from 1956)[2]. Most South American countries were considered LICs during the 1970's and followed and regularly updated the ACI-318.[b] In particular, Chile developed and systematically applied the seismic building code after the strong Valdivia earthquake of 22 May 1960 which caused 1655 deaths and the La Ligua earthquake of 28 March 1965 which caused 400 deaths.[c] Since then, the strict application of the seismic code has minimised the number of earthquake casualties in Chile and equally reduced the economic loss to the country.

The question can be posed: "Why are seismic codes not fully implemented in some countries?"
There are a variety of probable answers:

- The population and its leaders are not adequately aware about what the seismic code is.
- The majority of the buildings is constructed using traditional methods for low buildings that have proven to be adequately seismically resistant.
- Building codes or seismic codes are only applied to new government buildings.
- Although building regulations exist, these are not followed for a variety of reasons:
    1) People think the regulations make the building additionally expensive.
    2) People think that it is not possible to build strong enough against earthquakes.
    3) People believe that an earthquake will not happen during their lifetime.
    4) People consider earthquakes and death as an act of God, which is inevitable.
    5) There is no government control (in rural areas, being far away).
    6) Official control is costly or is faulty (open for corrupt practices).
    7) Building contractors are not adequately supervised on the quality of their work by the architects, municipality or the building owners.
    8) The codes are only applied to new buildings; old buildings are not retrofitted.
    9) People build on top of existing buildings and/or modify the ground floor design.
    10) Buildings are constructed for the purpose of selling with a profit. After change of ownership, the responsibility of the designer and builder is formally/legally ended.

All of the above issues can be addressed by improving public awareness about why earthquakes occur and how constructions can be strengthened.

This paper lists a number of common questions and provides answers without being too technical. It briefly reviews the different aspects of earthquake forces and provides ideas on how to improve the application in Himalayan countries such as Nepal and Pakistan.

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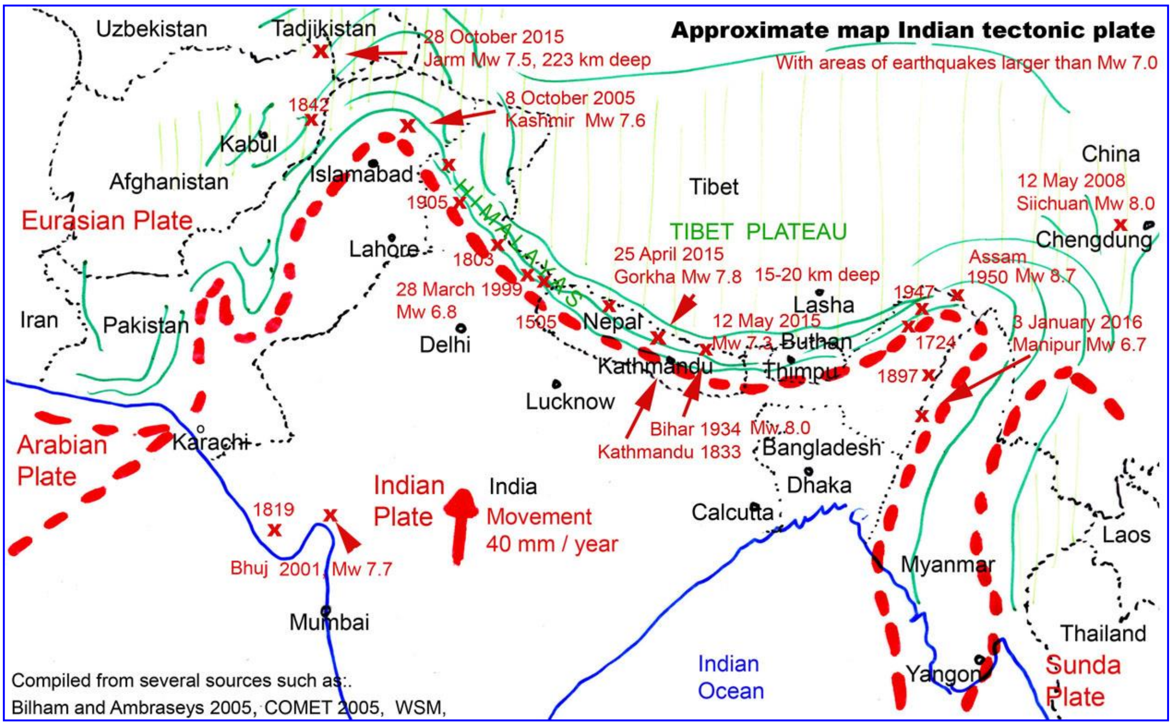
[1] As a result of the USA earthquakes: Santa Barbara in 1925 and Long Beach in 1933.
[2] The author co-translated and developed in 1975 the Ecuadorian seismic code on the basis of the ACI-318-'71. The Mexican, Venezuelan and Columbia codes had the same ACI-318 standard.

1. Where do the Himalayan earthquakes occur?

The earthquakes in the Main Himalaya Thrust Fault occur along the subduction zone of the Indian tectonic plate, where this Indian Plate gradually bends down (or is pulled down) and sinks under the Himalaya mountain range and the Tibetan Plateau of the Asian tectonic plate. The sketch map gives the approximate borders of the Indian Plate and a number of the largest earthquakes (>Mw 7.0).

On the map the three largest earthquakes near Kathmandu are indicated: one in 1833, 101 years later the Bihar earthquake in 1934, 81 years later on 25 April 2015 the Gorkha earthquake and on 12 May 2015 the Kodari earthquake. From the meagre statistics before 2015, the possibility of a large earthquake being due for the Kathmandu valley region was repeatedly mentioned by scientists. With the current statistics, it can be assumed that the next large earthquake will strike in about 75 years, although other scientists indicate that this may happen earlier.[d] The frequency of tectonic earthquakes is very difficult to predict when no detailed geological and seismic data has been collected over a long period. Calculations about the time and force of future earthquakes therefore remain estimates.



The Indian tectonic plate moves about 3-4 cm per year northwards, causing pressure to build up where the kilometres-thick rock layers of the earth's crust bend down. Rock has some elasticity and will compress, but when the forces exceed the elastic limit, the deep rock layers may crush and suddenly slip deep down (this location is called the hypocentre), which is felt on the earth surface (the epicentre) as a series of earthquakes. Series of smaller earthquakes from areas next to the first hypocentre will follow until the various tensions in the deep rock layers are released. After the 25 April 2015 Nepal earthquake, this process took several weeks with one larger earthquake on 12 May and hundreds of smaller earthquakes in the following months.

While the hypocentres of these two recent Nepal earthquakes and the 2005 Kashmir earthquake were estimated at 15-19 km deep, having a limited epicentre area, the hypocentre of the recent earthquake of 8 October 2015 in Afghanistan was 223 km deep causing a large epicentre on the surface.

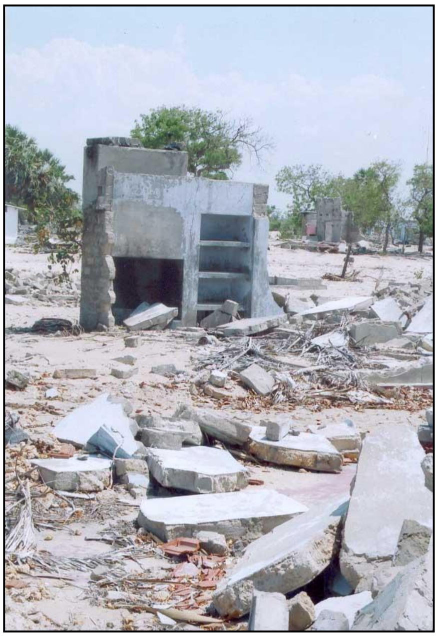
2. What is the purpose of a seismic code?

The seismic code is designed to strengthen buildings and infrastructure with the objective to protect life and property in the event of an earthquake. The Earthquake Engineering Research Institute (EERI) of India formulated the expression: "Earthquakes Do Not Kill People, Buildings Do".

Generally, people do not die because of an earthquake, but because of being inside **weak buildings** that collapse during earthquakes. A number of people die in **landslides**[3] and due to **rock fall** during an earthquake; while only a small number of people dies because of **heavy furniture** falling over inside buildings. **Tsunamis**, caused by earthquakes in the ocean floor, often result in a very high number of lives lost. ***All the above bold-printed aspects*** require specific technical and organisational measurements to prevent or avoid them.

The large tsunami of December 2004 caused approximately 230,000 deaths and 1,74 million displaced people.[e]

With the tsunami of 2004, whole villages have been swept away in Indonesia and Sri Lanka. Specific information has been developed on how to build safer houses in safer locations along coasts where tsunamis occur. In addition, early warning systems have been developed and implemented which allow people to evacuate to higher sites in time.
These tsunami measurements and regulations are usually not part of the seismic codes. However, the separate documents have had an influence on village planning and house design in the coastal areas.



Picture from coastal area in Sri Lanka 2005.

The main purpose of the seismic code is to provide rules for designing and making calculations of buildings to avoid the building collapsing during a maximum earthquake[4] and for essential buildings to be able to continue to operate. A secondary purpose of the seismic code is to minimise economic damage. Buildings that collapse or are severely damaged often means a loss of one's life investment and an economic set-back for a country. In those cases, the road to recovery is long. Such a large economic set-back is demonstrated from the 2010 Léogâne, Haiti earthquake[f] with an estimated damage of 120% of the GDP and the 2015 Gorkha, Nepal[g] earthquake with an estimated damage of 50% of the GDP.

The seismic code provides directives and regulations about the attachment of heavy furniture, such as high bookcases, boilers and water tanks. *"According to a study from the University of California in Los Angeles, 55% of the injuries during the 1994 Northridge earthquake was caused by falling furniture or objects, and several people died as the result."* [Quote: http://earthquakecountry.org/step1/].

[3] In Gorkha, Nepal, the whole village of Ghodabata disappeared under a mudslide, killing over 250 people.
[4] **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 PGA*g* 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.

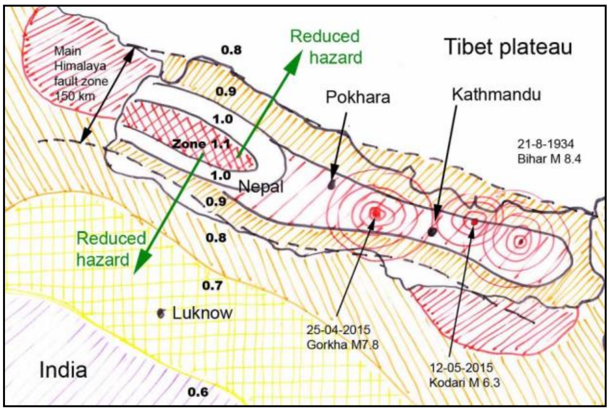
3. To what extent are buildings and infrastructures to be strengthened?

By strengthening buildings and infrastructure the loss of human and animal life, and the loss of economic investments or value, by a major earthquake can be avoided. To reinforce all constructions against damage during an earthquake will be extremely costly. The earthquake is the strongest in the epicentre, with the intensity decreasing with distance from that point. At a horizontal distance of two times the depth of the earthquake, the strength can be about 50%. However, it cannot be determined with certainty where the earthquake will occur. Following the earthquake design code creates buildings that will **not totally collapse at the maximum expected earthquake**. However, building damage can still occur, often to such an extent that it cannot be repaired economically. Variations between the design strength of a building and the reality may exist due to the quality of the foundation and execution of the construction, aging, occupancy loads and structural modifications.

People accept a certain level of risk of dying early in any year when smoking many cigarettes (1 in 200), driving a car in traffic (1 in 10,000) or travelling by train in Europe (1 in 500,000).[h] For building collapse due to earthquake and subsequent death, people seem to accept a risk of 1 death per 1,000,000 persons exposed.[i] The level of acceptance or Risk (**R**) in a given earthquake zone is defined by the equation: **R = H*V**, in which **H** is the Hazard level and **V** the Vulnerability.

The hazard level **H** increases, for example, when the building is close to a geological fault, built on soft soils that can liquefy, or built near landslides zones and under rock fall.

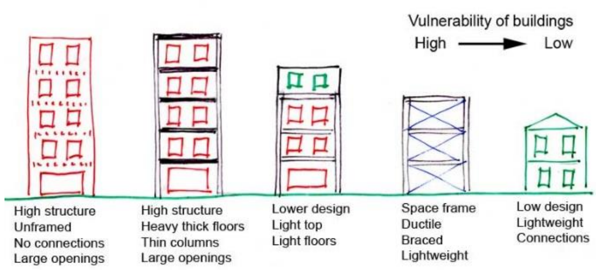
This sketch of Nepal indicates the main Himalayan fault zone between the interrupted lines. Within this zone, the value Z = 1.1 indicates the highest hazard. Moving towards India reduces the earthquake hazard in Nepal to Z = 0.9 and in India further to Z = 0.6.



Sketch after Nepal National Building Code NBC 105: 1994, Seismic Design of Buildings in Nepal.

The vulnerability (**V**) is related to the degree of loss with a building collapse. For example, in large buildings where many people can assemble, the vulnerability is greater than with single occupancy.

In addition, the shape and structural method of the building determine its vulnerability. A lightweight, low building with a ductile or strong frame is less vulnerable than a high, heavy building without structural reinforcements or good connections between floors and walls. The amount of openings on the ground floor also determines to a large extent the vulnerability. Buildings constructed on base-isolation, which avoids that earthquake movements are transferred to the building, have the smallest vulnerability.



Next to the hazard level, the seismic building code has many criteria to determine the vulnerability of buildings. The calculation methods need to be adjusted for each of these criteria.

4. What is the relationship between a Building Code and a Seismic Code?

Building codes are designed to create quality assurance and durability of the built environment, with the objective to minimise economic loss due to material and structural deterioration and to provide basic comfort and safety conditions. Building codes also regulate administrative aspects, such as extending building permits, and technical aspects, such as material quality, minimum space requirements, fire safety, illumination, ventilation, access, etc. The net floor loads and external wind/snow loads are indicated, but the building code does not provide the strength calculations.

The seismic code is an extension of the general building code. The rules and regulations of the general building code are a prerequisite for the application of the seismic code. If the steel reinforcement in concrete is correctly designed according the seismic code, but the concrete quality does not conform with the building code, the construction will not be strong enough. Building codes define material quality and regulate the control on the design and inspection of the building site to ensure that the contractor or self-help builder follows the design and material specifications. In some seismic codes, the material qualities are repeated or qualities elaborated upon.

In nearly all earthquake-prone areas, building codes are complemented by seismic codes, specifying the design aspects, calculation methods and strength values of primary and secondary structural elements to avoid building collapse during an earthquake. Haiti did not have a seismic code.

In countries where building or seismic codes have not been adequately implemented (Haiti, Pakistan, China and Nepal), large loss of life and economic set-back has occurred, while countries where seismic codes are strictly enforced (USA, Peru, Chile, New Zealand and Japan), the loss of life has been minimal.[j] Generally, the extent of compliance or non-compliance to the seismic codes only becomes evident after a major earthquake event.

The photos are from the Balakot shopping area after the 2005 Kashmir earthquake in Pakistan.

Non-adherence to building codes often results in poor concrete quality.
Non-adherence to seismic design principles results in design errors, large weights (mass) of the construction, faulty relation between beams and columns and the non-ductile sudden collapse of columns due to non-caging at the maximum moment areas (photo right).

5. Does the seismic code detail building materials or constructions?

As previously mentioned, the seismic code is an elaboration of the general building code. In most building codes, the quality and strength of building materials, such as steel, timber, concrete and bricks are specified. In many seismic codes, the most relevant building material strengths are mentioned or a referral is made to the building code. In some seismic codes, other characteristics of key structural building elements are mentioned, such as the shear value of a material and the friction coefficients between different types of materials, which are required for detailed calculations.

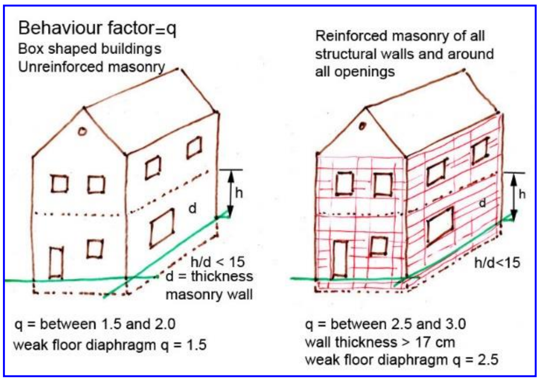
The seismic codes make a distinction between primary and secondary structural elements.

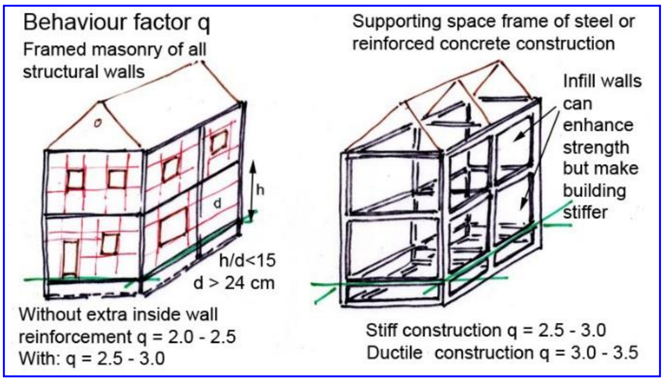
- Primary structural elements consist of the entire support system of the building that needs to resist the earthquake forces and prevent collapse.
- Secondary seismic elements are structural elements, but not part of the structural support system that resists the earthquake forces. These can be chimneys, parapets, awnings, balconies, ornaments and inside walls. The collapse of both primary or secondary elements can cause victims. The seismic code specifies strength values for both these primary and secondary structural elements, as well as attachment values for these secondary elements.

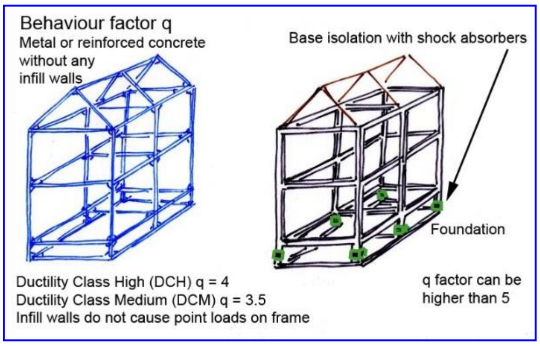
The seismic codes make distinctions between different type of construction methods because each different construction designs have different responses to the earthquake movements.

- Stiff building designs (brick, concrete) result in larger forces in the construction during an earthquake than flexible or elastic constructions (steel, timber, bamboo).
- Ductile buildings allow deformation of the support structure without collapse. Because of the deformation, a large part of the earthquake shock is absorbed.

Building constructions are grouped into several categories, each having its own behaviour factor *q*.[5]







In the older seismic codes, the K factor was used to define the type of construction. The K factor is in the more recent seismic codes given as a *q* factor and used in a different formula, but with the same purpose to define the overall construction strength.

The strength of the floor diaphragms and their attachments to all the supporting walls or columns has an influence on the *q* factor.

[5] **Behaviour Factor *q*:** Factor used in the strength calculation as K or *q* to reduce the forces. This factor is low for box-shaped and stiff buildings (masonry and reinforced concrete), and higher for other types of structures.

6. Have seismic codes separate documents on infrastructures?

Seismic codes often have separate sections on bridges, dams, retaining walls, elevated tanks, power lines and other infrastructures. These infrastructures often have a higher safety or importance factor (*i*)[6] than general housing because their collapse can cause additional damage (e.g. breaking dams or fire in fuel stations). These infrastructures need to continue to operate after the earthquake.

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

In addition the Indian Society of Earthquake Technology (ISET) and the Indian Association for Earthquake Engineering (IAEE) have published simple guidelines for the construction and retrofitting of low-rise and non-engineered buildings.

The Nepalese National Building Code (NBC)[m] dates from 1994 and comprises a set of 23 codes following the Indian code. The Nepalese seismic code-related documents include:

- 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 Seismic Provisions in the Pakistan Building Code are compatible with the Uniform Building Code (UBC) 1997 of the United States of America (USA), the American Concrete Institute ACI 318-'05 and other recent codes. It includes new materials, new construction systems and incorporates the following chapters:

1: Scope 2: Seismic Hazard 3: Site Considerations 4: Soils and Foundations 5: Structural Design Requirements (with divisions on dead and live loads, snow, wind and earthquake) 6: Structural Tests and Inspections 7: Structural Concrete, 8: Structural Steel 9: Masonry 10: Architectural Elements 11: Mechanical and Electrical Systems

The Structural Eurocode 8 programme comprises the following parts:

- EN 1990 Eurocode 8: Basis of structural design
- EN 1991 Eurocode 8, part 1: Actions on structures (including loads)
- EN 1992 Eurocode 8, part 2: Design of concrete structures. General rules and rules for buildings
- EN 1993 Eurocode 8, part 3: Design of steel structures
- EN 1994 Eurocode 8, part 4: Design of composite steel and concrete structures
- EN 1995 Eurocode 8, part 5: Design of timber structures
- EN 1996 Eurocode 8, part 6: Design of masonry structures (including various types of masonry)
- EN 1997 Eurocode 8, part 7: Foundations, retaining structures and geotechnical design
- EN 1998 Eurocode 8, part 8: Design of structures for earthquake resistance
- EN 1999 Eurocode 8, part 9: Design of aluminium structures

There is a National Annex per country in Europe with the local earthquake zoning.

[6] **Importance Factor *i* :** Factor used to enhance the factor of safety of special buildings. 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 building strength. The definition of the importance can vary slightly per country.

The above few examples of seismic codes of countries illustrate five aspects:

1. The seismic codes have not been developed in a single year and new chapters or parts are added and eventually legalised in subsequent years. The exception is the Pakistan Seismic Code, which was developed and published as a complete new document in 2007 after the 28 October 2005 Kashmir earthquake to replace the older 1986 code.
2. Seismic codes are often updated after a major earthquake disaster, like the Pakistan code.
3. Depending on the building stock, building practice and soil conditions in a country, special sections are further developed. In the USA, South America, Europe and New Zealand, the lightweight earthquake-resistant timber constructions have special sections, while in countries where bamboo grows, the good seismic properties of bamboo may result in special code sections. In the Himalaya, landslides and foundation failures are common during earthquakes and special sections may be further developed on these issues.[7]
4. Several countries like India, Peru and Chile have guidelines on construction techniques, while in Peru animated, easy to understand documents were developed. Nepal has "Mandatory Rules of Thumb", which are not presented as building law or made obligatory.
5. In the Himalaya zone, India has an extensive guideline on retrofitting of existing buildings covering various construction types such as non-engineered, masonry, concrete and steel constructions.[n] In Indonesia, a manual on retrofitting for schools has been developed by Save the Children and the Institute of Technology in Bandung.[o] After the 2015 Nepal earthquake, the Nepal Society for Earthquake Technology (NSET) compiled a document on retrofitting of reinforced concrete frames.[p] In Bhutan, special documents and guidelines are being developed in relation to the retrofitting of buildings.[q]

In all the Himalaya countries, the number of non-engineered and engineered constructions that were built without considering any seismic code is much larger than the constructions built according to the seismic code. The seismic code is often only applied in large cities, since adequate engineering skills and supervision is readily available. The effect is that the rural areas are highly vulnerable for large earthquakes, which was shown in both the 2005 Kashmir and 2015 Nepal earthquakes.

Although seismic codes apply to both old and new buildings, retrofitting or reconstructing all the non-complying buildings is a massive task and requires very large capital investments by the public and government; funds that are seldom available.

Nepal – rural and urban unreinforced masonry (URM)

Following several earthquake disasters, it has been observed that old buildings which were not retrofitted according to the seismic code collapsed and caused the largest number of casualties.

[7] One of the assessments of the 2005 Kashmir earthquake was that many buildings failed due to foundation failure. Because concrete, stone and brick masonry are heavy materials, constructions in these materials on unstable slopes lead to foundation failure and building collapse. Many people constructed these buildings on marginal land, such as sloped areas. In these cases, building and seismic codes need to include site planning and slope stabilisation, both in relation to the mass of the constructions.

7. What are the differences between the seismic codes used?

In the Himalaya region, various countries follow the American Concrete Institute (ACI 318) calculation methods for the seismic code. However, these calculation methods have developed over time and the newest code version provides more refined calculations. This is important for high-rise buildings (>20 m) and constructions with increased flexibility and elasticity. For low-rise buildings (<20 m) and stiff constructions such as masonry and most reinforced concrete, the older **static linear** or **push-over methods** of calculation are adequate and only show small differences in the seismic loads as compared to newer **elastic response spectrum method**.[8] For higher buildings, the static linear push-over calculation methods cause over-strengthening of the structure as compared to the elastic response spectrum method of calculation, which is a dynamic analysis whereby the response of several modes are determined and combined.

The former Indian seismic code IS:1893-1984 described two methods of calculation: the traditional (static) **Lateral Force Method** and the **Response Spectrum Method**. The newest 2002 version (IS:1893-2002) also includes the static **Seismic Coefficient Method**.[r]

The 1994 Nepal NBC 105 describes two methods for calculation: the **Seismic Coefficient Method** (static) and the **Model Response Spectrum Method** for dynamic analysis.

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 20 m (<20 m) and structures with high regularity (redundancy) up to 30 m high (<30 m), the **static analysis** may be used. For other or larger buildings, the **Spectral Response Method** is used.[s]

The choice between the calculation methods depends on the skills of the engineer, the height of the building and the regularity of the building in all three axes (2 horizontal and vertical). In the rural areas where buildings are seldom higher than 20 m (= 6-7 floors), the static method is mostly used.

For low residential buildings (<10 m = 2-3 floors), general calculation rules for the minimum wall section on the ground floor can be used to assess the resistance to earthquakes. In Mexico, Peru, Chile and Argentina, the net cross section of the walls (Wall Density Index) at the window level of the ground floor needs to be calculated.[t] This cross section needs to be measured in the two horizontal directions, whereas the value differs for each hazard zone and type of masonry materials used. This is based on the need for shear walls, which have to withstand the horizontal earthquake load in the plane of the walls.

When the minimum wall section does NOT comply, the entire building needs to be calculated according to the seismic code.

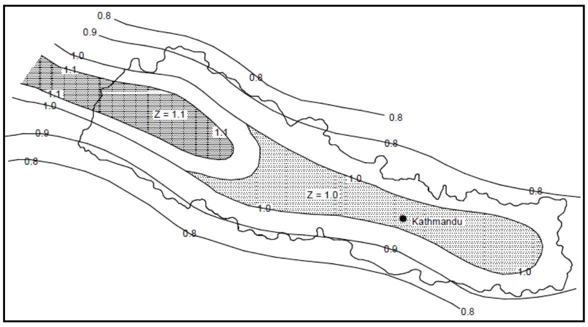
[8] All calculations are subject to the interpretation of the engineer and the possible variations in the material qualities and the quality of the execution of the construction. These variables are compensated with safety factors in the strength calculations. The use of the newest calculation methods, having smaller safety values, can only become cost-efficient for low-rise buildings with guaranteed construction quality.

8. Do all buildings require the same level of strength?

The strength level of buildings depends on three main factors:

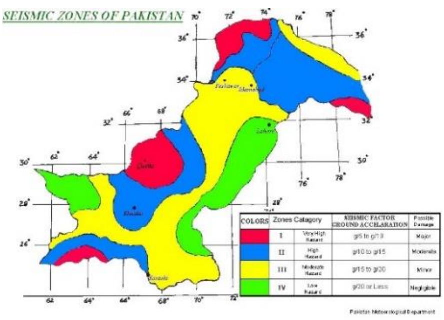
A. The earthquake zoning where the building is situated (*zoning factor Z*).
B. The soil type on which the building is constructed.
C. The importance of the building (*the i factor*).

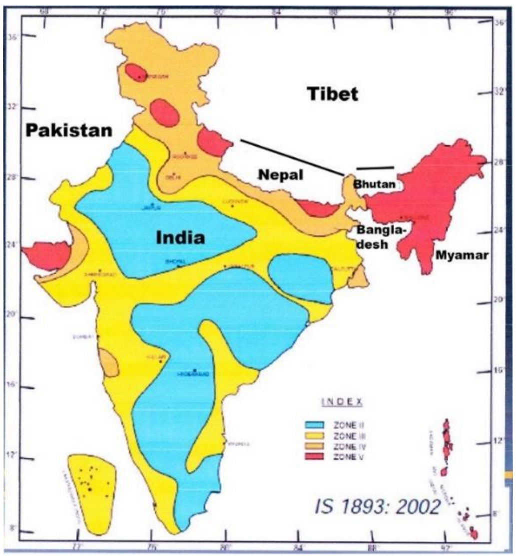
For Nepal, t**he earthquake zoning** Z factor for the Kathmandu region is 1.0, while for the zone near Pokhara, the Z factor is increased by 10%, to Z = 1.1 (darker grey). The zoning factor Z is a multiplier in the formula for the calculation of the earthquake load on the building.

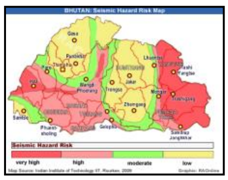


Zoning Factors Z in Nepal
The friction zone of the subduction of the Indian tectonic plate under the Tibet plateau lies under the grey and central area of the country.
The central zone left is considered having a 10% greater earthquake load than Kathmandu. The Z factor is taken here as 1.1
Source: NBC 105 document

The next earthquake strength and exact location nearby Kathmandu town or valley cannot be determined with precision. In the definition of the seismic building codes, certain safety margins have been assumed. In addition, the earthquake force on any building foundation depends on the distance from the epicentre and the soil type because earthquake waves travel at different speeds through the earth and absorption of the force occurs during this travel. Generally, the zoning follows the combined strength contours of all the earthquakes in a country. This creates a zoning that follows the Himalayan fault line.





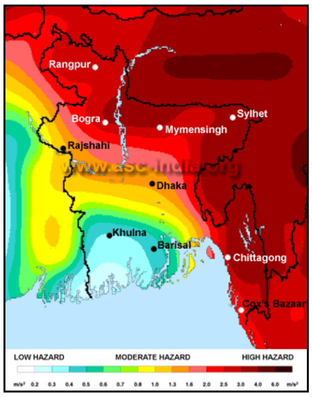


Above map: Very detailed Bhutan zoning.

Pakistan and India seismic code zoning maps at about the same scale. The Kashmir zone is on each map, but with different values, size and colours.

In addition, the Nepal zoning map does not depict exactly the same values across the political borders with India. The same type of differences occurs between the country maps in the Eurozone.

The earthquake zoning maps for Pakistan, India, Nepal, Bhutan and Bangladesh have different numbering, values and level of detail. However, in combination with the calculation methods given in each of the seismic codes in those countries, about the same building strength should result. In Bhutan and Bangladesh, the mountain ranges have an important influence on the seismic zoning.



Seismic code map from Bangladesh. Note the narrow zoning width in two locations. Maps are periodically adjusted when more information about the geology and earthquake events is gathered.

The **top 20-30 m soil type** on which a building is constructed has an important influence on the earthquake force and the propagation of the shocks. Micro-zoning will depend on the top and sub-soil conditions (top 20 m and possibility of liquefaction). Soft elastic soils may increase the horizontal movement and, with that, the forces and duration of the vibration, leading to larger forces in the building construction. The vibration time of the building itself is a determining factor for the load on the building. Soft soils (not rock), on the other hand, will also have some damping and reduce the strength of the shock propagation over longer distances, leading to lesser forces. Wet soils which are under vibration may liquefy, leading to the sinking of entire buildings (foundation failure).

Earthquake zoning and the expected maximum earthquake[9] strength depends on the deep geographical situation in a country and the more superficial soil conditions (top 20-30 m). Determining the maximum earthquake which may occur in the future involves risk calculations and the acceptance of the fact that in the very epicentre[10] buildings may collapse. Setting the values for the earthquake zoning in a country is balancing the possible economic aspects of damage and reconstruction costs.

For example, the earthquake zoning in Pakistan Kashmir was in 2005 either not classified or deemed to be Zone 2 (low to moderate risk), while it should have been classified as Zone 4 (high risk) as given in the Chapter 16 of the 1997 Unified Building Code (UBC).[u]

Apart from the above-mentioned factors, it seems that buildings on the top of hills receive a larger horizontal acceleration than buildings in the valley.

Internet photo: Financialexpress.com of Nepal.[11]

[9] **Maximum Earthquake:** According to tectonic plate and 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 PGA*g* value is used in the calculation of the forces.

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

[11] See: www.financialexpress.com/topic/nepal-earthquake PTI May 4, 2015 12:26 PM. Illustration with article: "3 Survivors found in Nepal as earthquake toll reaches 7,056"

The importance of the building (*the i factor*) determines the additional safety strength for the construction. Due to the vulnerability of buildings where many people can gather together, the earthquake risk is considered to be higher than for buildings not providing essential services or where only few people (or animals) gather. All building codes apply factors to strengthen structural performance for essential public buildings and services (see table below). The values of these factors will differ between countries and will be related to the value assigned to the structure and the earthquake zones.

The ACI and Eurocode 8 not only make a distinction in the importance factor of buildings per category (e.g. schools and hospitals), but for the total number of occupants as well (e.g. 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 Eurocode 8 has an annex with the earthquake intensity zoning maps per country. There are small variations in strength across political borders.[v] These differences are similar as shown in the Indian zoning map.

The following table shows some increased strength requirements based on the importance of various building 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. These values are additional to the values for the respective seismic zones in a country and for the soil types.

	Importance Factor *i*					
Description of Construction Categories	**Chile**	**Indian 2002**	**Nepal 1994**	**Peru[w]**	**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 storeys. 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 storeys 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, firefighting 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 with occupancy of more than 300 persons.

The table above shows existing differences between the *i factor* of the codes. Chile has a lower importance factors than other countries, but higher zoning factors than other codes, resulting in an overall higher safety value and subsequently less building damage or collapse. The Indian codes are the only ones that specify housing of "Very Important People" with a higher safety margin.

The Eurocode 8 and the ACI-05 greatly relates 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. Snow load is important at high altitudes in the Himalayas.

The conclusions regarding seismic codes worldwide are:

- They follow the same calculation techniques and include simple calculations that can be applied for low-rise buildings.
- For low-rise and stiff (brick masonry and RCC) box frame buildings, the simple static or push-over calculation methods can be used.
- The codes are regularly updated with the newest codes from more advanced countries.
- The load factor on the structure depends on the national earthquake zoning (*Z*), the soil conditions of the top 20 m, and the importance factor (*i*) assigned to the structure.
- Countries have slightly different interpretations about the importance factors and zoning.

Adapted from: Earthquake Engineering Research Institute EERI special report, page 7.[x]

Related to low-rise and low-occupancy buildings in remote or rural areas:

- In several countries (e.g. Peru, Chile), low-rise residential buildings do not have to be calculated according to the seismic code if the minimum wall section at ground floor window level complies with the minimum values as described in the regulations.
- In most countries (e.g. Nepal, Pakistan, Tajikistan, Chile, Peru), there is no municipal or government control on the design of low-rise buildings in rural areas or on the proper execution of these buildings by the contractors or self-help builders.
- In several countries (e.g. Chile), there is adequate government control on seismic-resistant construction of public buildings, such as schools and hospitals.
- In several countries (e.g. Nepal, Pakistan), there are no easy to understand illustrated guidelines in the local language with examples on where or where not to build, or how to build low-rise residential buildings.
- In some countries (e.g. India, Indonesia), there are illustrated guidelines on how to retrofit existing buildings to make them more earthquake resistant, without calculation examples.
- In most countries (e.g. Nepal, Pakistan, Japan, Peru, Chile, Haiti), the most casualties are caused by the collapse of buildings that did not comply with the seismic code, including many rural houses that were not retrofitted according to the seismic code.

For most low-rise, non-earthquake-resistant buildings in high-risk earthquake areas, it is usually not very economical to strengthen and retrofit such buildings, unless they are of high historic value. Due to low labour costs, it is often more cost-effective to reconstruct the entire building according to the regulations and calculations of the seismic code, especially when materials can be reused.

The large economic challenge of a country and its inhabitants is to retrofit or reconstruct all rural low-rise housing that do not comply with the seismic code.

9. Does retrofitting require the same strength as new buildings?

Yes; in principal all buildings should comply with the seismic code of a country. However, because most of the buildings have been constructed before the publication of the first or latest seismic code version, it will require enormous private and public investment to upgrade the entire building stock. Large-scale retrofitting must strike a balance between desirable and affordable. In LICs, the affordable aspect is the large restraining factor. Retrofitting or reconstruction can be undertaken in phases.

When calculating a structural design of a building, the average strength values of timber, steel and concrete are used. These values are derived from material tests and usually have a reasonable safety margin. Due to knots and fissures in timber, as well as differences in age within each timber section, the strength safety margin of timber is usually large (50-100%). Steel components have a small safety margin because the quality can be precisely controlled during the manufacturing process. Cast concrete in reinforced concrete constructions will have varied qualities due to cement and water contents, compaction during casting and the curing process. On average, construction materials are about 1/3rd stronger than the calculated values. Hence, the actual construction may often withstand larger forces than the calculated forces when properly built with good materials.

When assessing existing buildings, their theoretical strength can be calculated on the basis of the strength standards of the building materials used, but the real strength may be 1/3rd higher considering the safety margin of these building materials. When such a construction can theoretically withstand 2/3rd of the maximum earthquake load, it may not collapse under the maximum earthquake load. Moreover, the risk that this maximum earthquake will occur within the next 50 to 100 years is also rather small. The first phase (several years) of retrofitting can therefore be limited to 2/3rd of the maximum earthquake load. This is the recommendation of the Royal Commission, based on research after the large Mw7 Earthquake in Christchurch, New Zealand.[12 + y]

The above strategy will save large initial retrofitting costs on a national scale. The New Zealand Royal Commission recommends that owners of earthquake-prone buildings that do not comply with minimum 1/3rd of the required strength should either demolish those buildings or retrofit them to minimum 2/3rd of the required strength within a given time span.[z] This time span can vary depending on the estimated strength of the building and the possible risk of the building. If the buildings are located in a high risk area, such as under potential rock fall, landslide or flooding area, these buildings have to move. In a second phase, the retrofitted buildings should be further upgraded to the full 100% earthquake resistance within another time span. This also means that retrofitting to the 2/3rd value of the required strength should not limit the possibilities of further strengthening of the building.

Directly after a large earthquake, immense efforts are required to repair the damage. If the time span between very large earthquakes in the same area is estimated (for example) at 30 years, the 2/3rd retrofitting should be realised within 10 years and the full strengthening within 20 years, to allow a sufficient safety margin.

When the above type of regulation is applied to Nepal, it will probably take 50 years before all the buildings in the Kathmandu area are upgraded to full seismic code standard. This is based on the assumption that there is an approximate time span between the major earthquakes in the middle section of the Himalayan fault line around Kathmandu. The earliest recorded Kathmandu earthquake was in 1833, the Bihar earthquake was 101 years later in 1934 and now, 81 years later most recent

[12] This research after the Christchurch earthquake of February 2011 showed that buildings retrofitted and strengthened up to 67% performed moderately well, but buildings strengthened to less than 33% did not perform significantly better than buildings not strengthened at all.

earthquake. Taking a safety margin, the next large earthquake of M8 or there about can be expected for the Kathmandu valley as from 2090 (2015 + 75 years).[aa]

With a few million buildings in Kathmandu valley, this is an immense task which will require huge investments and can obviously not be done in a few years. After completion of the ongoing emergency strengthening of buildings, a systematic assessment needs to be made of all other buildings and a new estimate of the possible maximum earthquake with micro-zoning of the Kathmandu valley.

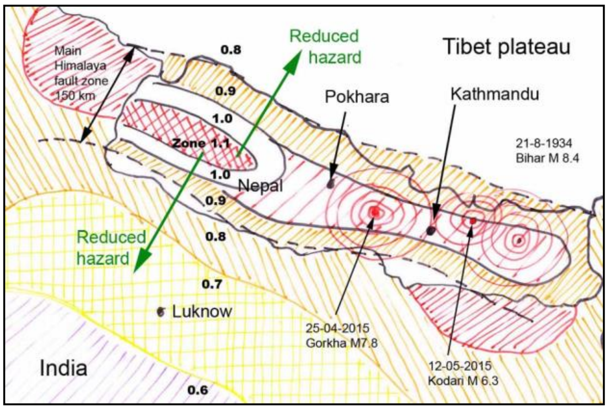


Photo of new buildings being built in soft soil areas of the Kathmandu valley. Most of these buildings would not withstand a nearby Mw7 earthquake with a Peak Ground Acceleration >4.0. The recent earthquakes produced a maximum PGA of about 0.25 in the north side of town, already causing several reinforced concrete frame buildings to tilt because of weak foundations and others to collapse because of poor structural design, lack of shear walls, etc.

The April and May earthquakes had only a limited effect on Kathmandu valley housing stock with a PGA < 2.5 in the most northern part of the city. This is similar to a light earthquake strength, although the horizontal displacement was very large (0.5 m in places). A Mw7 earthquake right under Kathmandu with a PGA 4.0 would have caused more than 100,000 multi-storey reinforced concrete buildings to collapse, which now have barely survived the current light accelerations (PGA <0.25).

Equally, an assessment needs to be made as to why there are no major earthquakes in the Pokhara and more western sections of Nepal. The installation of an interlinked network of acceleration meters would be one of the items needed. If large earthquakes are due in that region, economic investments for evaluating and strengthening buildings should probably have priority there. Currently there is no viable earthquake hazard assessment for the country as a whole, indicating the geographic zones where a large earthquake may soon strike.[bb] In addition, there does not seem to be a clear hazard management approach, such as detailed analysis of existing or residual stresses.

From the underlying data of the large regional map on page 5, it cannot be determined with certainty when new tension releasing earthquakes may occur in other regions of Nepal, being west to the Gorkha zone or east to the Kodari zone. Such will require continuous geological surveys and vibration measurements over the entire Himalayan zone.

10. What is required to ensure compliance with seismic building codes?

While seismic codes are often updated directly after the occurrence of a major earthquake with many casualties, these updates are most relevant for high-rise buildings and have little effect in the design strength for low-rise buildings. However, 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. Enforcement is impossible without adequate training on many levels, from the house owner to mason, controller and engineer.

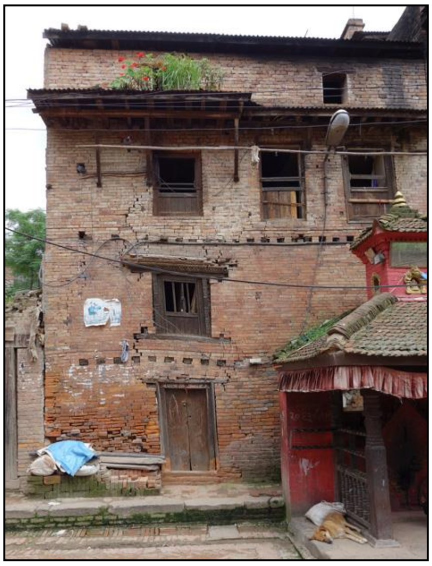
The second essential element is an administrative system to control the correct implementation of the building and the seismic codes. This can be: (a) public administration, (b) private enterprise or (c) community based. The modality depends on the financing options available, while for the community-based option awareness of the community is important, basically about the importance of avoiding building collapse.

From analysing the main data about building collapse, it is always the old buildings that were not upgraded or seismically retrofitted which collapsed. The identified problem here is that seismic codes are often only applied to new buildings, not to the existing building stock.

It will require a very large economic effort to upgrade the existing building stock in both urban and rural areas within any given time period. This will require tailored financing systems, but most rural households do not have access to finance. In areas vulnerable to landslides, rock fall, river blockage or liquefying soils, relocation of housing sectors will have a large impact, especially when land for housing is very limited, such as in many mountain communities.

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.

Seismically upgrading buildings also requires social and economic upgrading. Light, ventilation and sanitation is often poor in old houses, and staircases are narrow and steep. The space organisation and building performance aspects, such as thermal insulation and ventilation, need to be reviewed and upgraded. This is required to give the retrofitted buildings an economic lifespan of more than 100 years. When the combined costs of seismic and economic upgrading exceed the new building costs, it will be more cost effective to demolish these old buildings and realise new ones, unless the buildings have an additional historic or touristic value, such as temples.



Damaged old housing in Bhaktapur, Nepal, has an economic, historic (tourist) and user value. To upgrade these buildings seismically and refurbish them will far exceed the cost of an entirely new construction using the old bricks and windows.

11. Why does the general population need to be educated about the code?

The 10 points mentioned in the introduction are the main reasons:

- *People think they make the building additionally expensive.*
  The additional expenses range from 10 - 15% for a small cement-masoned building when it is well designed and constructed. The connections between the supporting structure and the floor and roof diaphragms need to be improved and large openings assessed. With the certainty that more earthquakes are coming, it is a good investment to assure survival.

  Especially when designing a new building, simple measurements can have a large impact on the overall structural strength of the building. House owners and masons should be aware of this.

  Retrofitting existing old houses that are poorly constructed from heavy materials (adobe, stone) may be rather costly. Removing the mass of those heavy materials is often necessary. Old houses may have other problems, resulting in the new stronger construction being far more cost-effective.

  The mass (stone, brick) of old buildings is often very large and masoned in mud paste only. By using the building materials from the original building and cement mortar with proper reinforcements, often twice the number of wall surface can be realised as compared to the demolished house.

Above (Nepal): no anchors between column and masoned wall caused this wall to collapse.

Left (Peru): by casting the column in between walls, the connection is much better and has no additional costs.

By masoning long anchors in the joints, ending in the column, the overall strength in the plane of the wall will be considerably improved and costs only little.

- *People think that it is impossible to build strong enough against earthquakes.*
  This is not true at all. Constructing according to the seismic code assures that the building will not collapse. However, if the building is at the epicentre where the maximum earthquake occurs, the buildings constructed according to the code may suffer considerable damage. That percentage of buildings reduces with the distance from the epicentre the PGA. By using base-isolation damage to tall buildings can be avoided completely.

- *People expect that an earthquake will not happen during their lifetime.*
  In the Himalayas and other zones where tectonic plates are colliding, this will not be the case. Small earthquakes occur all the time. Only the maximum earthquake may not occur. Buildings constructed according to the seismic code will have little or no damage with smaller earthquakes or further away from the epicentre.

This house in Gorkha district had no visible damage after April 2015 with the Mw7 earthquake, being located only a short distance from the epicentre. A few elements of the seismic code were applied, which were sufficient to withstand the large horizontal shocks. On the other hand, some elements in the buildings were not constructed according to the code, while these would have made the building even stronger without additional costs.

- *People consider earthquakes and their death as an act of God and is inevitable.*
  Nowadays it is very clear where the earthquakes come from, but scientists cannot precisely define the next epicentre or the actual strength and duration. With the collection of more data and surveys of the tension build-up in deep rock layers, better predictions can be made. Preventing earthquakes by deep underground explosions is being studied, but likely to be very expensive. It is currently more cost-effective to build according to the seismic code to avoid building collapse.

- *There is no government control (in rural areas, being far away).*
  This is an important reason why people who want to build a new house and the builders need to be aware about the potential of applying the seismic code. The basic rules for small low-rise houses are not very complicated and cause little additional expenses. Developing seismic-resistant standard designs, following these designs, and training of masons will be adequate for building seismic-resistant constructions.

  When house-owners are aware of their personal risk when living in a non-earthquake resistant building, they will have a vested interest in assuring quality construction.

  (Peru): trained and qualified masons, and experienced community members can assist local house owners-builders and contractors to verify the execution of the work on site. This way expensive government control does not have to be on-site.

- *The official control is costly or is faulty (open for corrupt practices).*
  This is an important reason why the house owner should take an interest in the quality of the construction and the life-time large investment which is being made. Study and information material should be readily available from all municipalities, as well as standard building designs. This is far less expensive than mobilizing inspectors who are only occasionally available.[13] The point here is that the application of the code should be desired and insisted upon by the building owner.

[13] While it is not possible to stock hard copies of all possible building designs in a municipality, the municipality (or Village Development Committees such as in Nepal) can have a communication link with a city-based organisation having access to designs posted on Internet. Chapter 12 explains a possible option.

- *The building contractors are not adequately supervised on the quality of their work by the architects, municipality or the building owners.*
  Having good building plans with photographs and 3D drawings of details and connections is an important step to allow the building owners to verify on site work. In a village environment, trained or qualified masons can be contracted to supervise the work of the building team. When the building owners are better aware of the need to build according to the seismic code, they will find ways to locally control the proper execution of their buildings.

Some of the problems of rural construction is the lack of machine mixing equipment for cement mortar or concrete. Hand mixing often results in added water and low quality, which will affect the overall strength of the construction. The use of machine mixers may be a requirement.

- *The codes are only applied to new buildings. Old buildings are not retrofitted.*
  This is the current practice, but unwise because those old buildings will collapse as is demonstrated worldwide. [14] Each country needs to make an assessment of the existing buildings as to whether or not they comply with the seismic code. The best way is to define the most common typologies of buildings and calculate their strength. Depending on the zoning, it can be decided to strengthen or demolish the buildings. In New Zealand, the decision was to immediately demolish or reconstruct all buildings that did not have 1/3rd of the required strength.

(Nepal): Many urban and rural buildings can be sorted under a specific typology and for each a strength calculation can be made. From many buildings, it can be easily assessed that they would not withstand any major earthquake. Most dry stone and adobe houses cannot be economically retrofitted and need reconstruction in a new design and on stable slopes.

- *People build on top of existing buildings and/or modify the ground floor design.*
  While the basis of a building may be properly designed, adding stories and removing shear walls on the ground floor both have serious negative impact on the building strength. Only education, control of building permits and on-site control of the execution can prevent these developments.

[14] Some details of major earthquakes are given in Chapter 13 with a comparative table. Although many casualties occur, by far most of them are caused by non-seismically designed and non-retrofitted buildings.

- *The buildings are constructed to sell with a profit. After change of ownership, the responsibility of the designer and builder is often formally/legally expired.*

  Some possible measurements are the following:

  (a) The legal responsibility of the design and executed construction should remain with the building company, also after the sale. In some countries, the time of the legal responsibility for the construction quality is limited, for example, 10 years in New Zealand.

  (b) The sale should not be permitted without seismic verification and certificate. This may signify that some retrofitting may be required when a new seismic code has been introduced after the building initially was completed.

  (c) Financing institutes should not finance buildings that do not comply with the code. This means that the building plans must be approved and the proper execution of the building is assured.

  (d) Insurance companies should not insure buildings that do not comply with the seismic code. This means that ample documentation and certification must be available about the building construction.

  (e) Renters should obtain a municipal certificate that the building is according the seismic code.

  (f) Modifications of the structural components may not be realised without due analysis by qualified engineers.

  The implementation of the above requires both education of engineers and architects, a building registration system, control on modifications and changing the national legislation. When the people who are going to live in these buildings are aware of the risk, they would support the legislation and ask for the certificates.

12. How would a village-based information system work?

When no architects, engineers or official building inspectors are available in the villages, and the villager (wanting to build a house) or masons still want information on how to build a better house, a Question and Answer System (Q&A) needs to be developed.

The following are suggestions on how to develop a workable Q&A system in a rural area that responds in detail to specific questions of villagers:

A. Each village needs to set up an information point, such as an info-shop with a local shopkeeper who sells equipment. The Q&A activity may attract various people.
B. The builder approaches the info-shop with a Question (Q). The info-shop operator helps to formulate the Q as precise as possible with the aid of a questionnaire form. This may include the size of the house to be built, number of rooms, sanitation, foundation soil type, slope, access, available materials, etc., and possibly a site plan or sketch. For this, the info-shop keeper needs to receive some training and the questionnaire forms.
C. The info-shop operator mails the detailed Q to the district headquarter (by bus operator), for example to an NGO who has Internet access.
D. The NGO may have a direct answer or can find the Answer (A) on specific Internet sites.
E. If the district NGO does not know the answer, it sends the Q to a national institute in the capital for detailed answering.[15] Possibly an extra cycle of Q&A with the villager (through the info-shop) may be required. The national institute posts the A on their website, accessible for all districts.
F. The NGO then sends the A in simple and well-illustrated local language to the info-shop. This may require translation. It would be beneficial for the NGO to send the translation also to the national institute so it can be posted on their website.
G. The A from the district NGO to the village info-shop should be supplied in two copies.
H. The village info-shop keeps one copy for its own record and gives the other to the requesting villager. The info-shop keeper explains the answer in detail to the villager.

In rural areas, the cost of this operation is far lower than an inspector driving around with a vehicle. With more similar Q&A, the cheaper the delivery of each answer becomes.

I. Upon delivery of the completed answer to the villager, the info-shopkeeper receives a small premium amount from the district NGO and from the villager. This premium from the NGO is initially subsidised, but annually adjusted (reduced).
J. Although the type of Q&A may be limited to seismic construction in an early stage, it can eventually be extended to agriculture, sanitation, health, finances, energy, etc. in the future.

This model means that the national government should develop the legal aspects of the code, while the national institutes should develop a series of standard designs of rural buildings, based on the many typologies and available materials. The designs should allow some minor modifications, have Bills of Quantity for each design and instructional manuals. These designs can be communicated to the districts through the Internet, while the NGO or districts can print these on demand.

The demand side is generated through the assistance of trained shopkeepers who helps the villager to define its needs. In some cases, local NGOs can further elaborate the demand and transfer this to a digital file for onward communication.

[15] When the system has been operating for awhile, similar questions will become apparent and the websites known. In that case, the NGO can directly answer the question without having to go through the National Institute. The websites should have a wide range of building designs on-line, instructional materials and manuals.

The following sketch gives the main phases of the communication process.

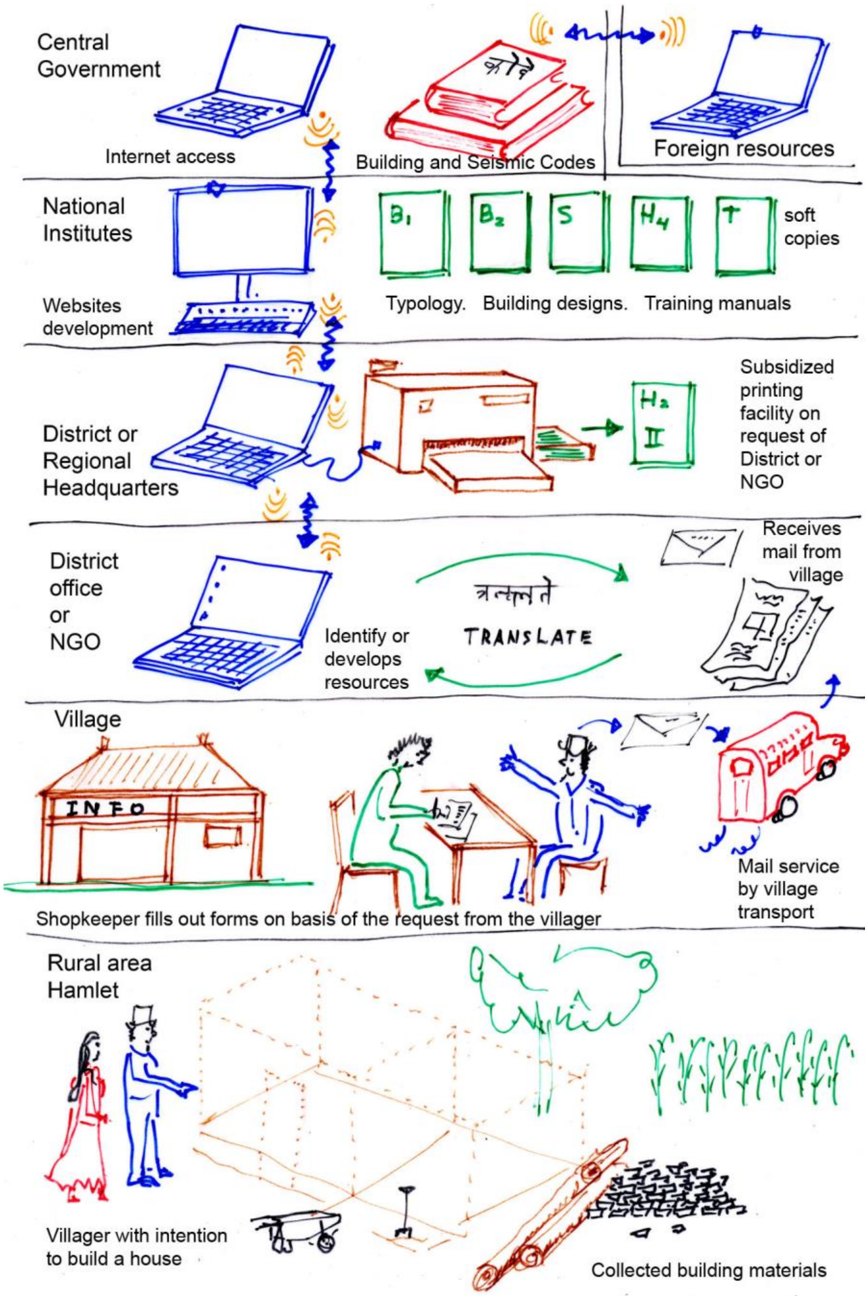
Optimum use is made of international recourses, such as existing seismic codes and legislation about retrofitting.

Depending on the local typologies, different detailed designs are made, as well as for more than one-storey height.

The form information from the shopkeeper needs to be digitized for onward mailing to district or national institutes when answers are not yet locally available in the data base.

The shopkeeper needs an initial training to assist the villager in the completion of the forms for assistance and mail this through the local transport means in the region. The villager may pay the mailing costs.

The answer is delivered back from the district to the shopkeeper and villager.



The shopkeeper can obtain an income by selling the villager supplies or building materials. Some of the building materials may be ordered through the same system from the district. Once the system is in operation, the agricultural or veterinary departments can join the mail and information system.

The low-cost information and supply network will be beneficial to the rural population to generate income. Only through good information, marketing and subsequent income generation will the villagers be able to retrofit or reconstruct their houses.

13. Can earthquake deaths in different countries be compared?

Yes, but there are many variables to consider. It is necessary to analyse the type of collapsed buildings (CB). From that analysis, it can be deducted which casualties occurred mainly from collapsed old buildings that never were upgraded to comply with the seismic code (SC) or from new buildings that also did not comply with the seismic code.

Table of several large earthquakes since 2005 with some data:
? Data not always verifiable of differs in various sources.

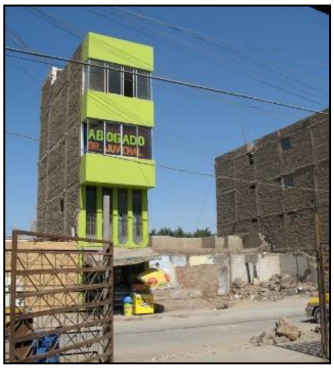
Year of Earthquake	Country	Max. PGAg	Deaths	fully Collapsed Buildings (CB)	Loss in % of GDP [cc]	Deaths per 1000 Collapsed Building (CB)	Type of Collapsed Buildings (CB)			
							Adobe Blocks	Stone	URM	Old RCC
2005	Pakistan, Kashmir [dd]	0.23	88,000	? 400,000	0.4%	220	+	+++	+	+++
2007	Pisco, Peru [ee] + [ff] + [gg]	0.49	519	33,000	>5%	16	+++	-	++	+
2008	Sichuan, China [hh] + [ii]	0.23	87,150	? 1000,000	?	87	++	?	+++	++
2010	Maule, Chile [jj] + [kk]	0.65	525	81,000	8-17%	6.5	++	-	++	+
2010	Léogâne, Haiti [ll] + [mm] + [nn]	0.44	222,570	105,000	>120%	2120	-	-	++	+++
2011	Christchurch Nw Zealand [oo]	1.88	185	2	≈10%	x	-	+	+	2
2011	Tōhoku, Japan [pp]+ [qq]	2.99	28,000	100,000	3-4%	28	-	-	+	+
2015	Nepal [rr] + [ss] + [tt] + [uu]+ [vv]	≈0.25	8,790	605,253	50%	14.5	+	++	+++	+
2015	Illapel, Chile [ww] + [xx]	0.25	15	270	0.15%	x	-	-	+	++

The observations about each of the earthquakes and compared with the 2015 Nepal are as follows:

The 2005 Kashmir earthquake occurred under the city of Balakot, which was totally flattened. The high casualty was to a great extent the result of slope failure and old, heavy, non-reinforced stone buildings and non-seismic designed reinforced concrete buildings.

In particular, heavy reinforced concrete constructions that are not designed with ductile areas where the maximum moments will occur are subject to sudden failure. In addition, buildings with thick and stiff concrete floors are subject to large horizontal earthquake loads.

Low buildings had thick concrete beams and cement topped roofs, but with thin columns having no caging in the maximum moment areas.



The 2007 Pisco earthquake caused in the rural areas many old adobe houses to collapse. In addition, old brick houses collapsed in the more urban areas. However, because all new houses were built according to the seismic code, the number of collapses is only 1/20th of the those that collapsed in the Nepal 2015 earthquake. Subsequently the number of deaths is equally small.

Framed masonry constructions having adequate ground floor design of the reinforced concrete construction obtained no damage.

The 2008 Sichuan earthquake caused massive deaths because it was located near a large urban area and the seismic code was never used to retrofit existing buildings. For a number of recent buildings, the contractors had used very poor concrete quality, while controlling officers did not verify the proper execution of the work (corruption).

The 2010 Maule earthquake had a relatively low number of casualties. *Quote: "A major factor is the strong building code in Chile and its comprehensive enforcement"* and *"The law holds building owners accountable for losses in a building they build for 10 years.*

The Maule earthquake (Mw 8.8) was twice as strong as the 2015 Nepal earthquake (Mw 7.8), but occurred just off the coast; therefore, reducing the area and impact on land by about 50%. Similar to Nepal, there were hundreds of large aftershocks over a coastal length of 800 km.

Map: https://en.wikipedia.org/wiki/2010_Chile_earthquake
The distance between Santiago and Temuco is approximately 800 km.

The 2010 Léogâne earthquake occurred right under a densely populated town. None of the buildings were constructed according to any seismic code, resulting in both an enormous death toll and an economic loss of about 120% of the GDP. The country will require 20 years to recover from this devastation, even with substantial foreign aid.

The 2011 Christchurch earthquake was very near the earth surface and right under the town, the reason why the PGA was very high. Some deaths were because of rock fall and pieces falling from buildings. The collapsed CTV building had 115 casualties. The engineering of that structure was minutely analysed and found that earlier retrofitting was non-compliant with the seismic code.

The 2011 Tōhoku earthquake had a PGA 10 times stronger than those of Pakistan, China or Nepal and a larger population density, but the earthquake occurred far off the coast. A combination of building type and application of the seismic code kept the number of victims relatively low. Most of the old (not retrofitted) buildings that collapsed were designed with light, thin timber frames, but with heavy roofs to better withstand tornadoes.

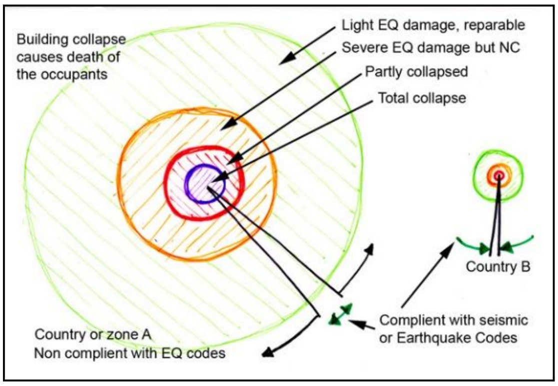
The 2015 Illapel earthquake was also off-coast, but since 2015 Chile continued to enforce the seismic code, resulting in only a few casualties who died in non-retrofitted building collapse.

The conclusion of this shortlist of major earthquakes is that buildings constructed according the seismic code do not collapse and subsequently seldom cause deaths. In addition, it keeps the economic damage low, allowing fast economic recovery.

14. What are the main points based on these answers?

Comparing earthquake disasters requires the comparison of many aspects, such as the strength of the earthquake (Mw), depth of the hypocentre, soil structure (top 20-30 m) and the distance between the epicentre and the buildings. Comparing the number of collapsed and subsequent casualties depends greatly on the overall population density and the density per building, and whether or not the seismic code was applied to new buildings as well as for retrofitting old buildings.

Relation between earthquake damage and seismic code compliance



The sketch shows the differences between 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.

A. The implementation or the modification of existing codes and standards requires local legislation and extensive capacity building of the controlling and implementing agencies (private, institutional and government). However, the general population must be aware of the risks and implications of buildings that are not adequately seismic resistant and may collapse with a maximum earthquake. In this way the educated people living in the houses will demand adequate building control.
B. When the general population is aware of the principles of the seismic code and relatively low cost of the additional strengthening of buildings, house owners will demand the implementation of the seismic code. In addition, they will not modify the structure of the building without due consultation with engineers or qualified authorities.
C. Architects, engineers, building contractors and certifying officers should remain legally and financially responsible for an extended period for the constructions realised. This period should not be shortened by the sale of the building or the bankruptcy of companies. This also implies that there is a good registration system of constructions. This will encourage such parties to be more careful in design and building site supervision.
D. The large damages and death toll in Pakistan and Nepal give an indication of the importance to the national economy when buildings do not meet the code standards. For small and low-income countries, the economic set-back is very large (Haiti, Nepal).
E. Local governments should realise the economy of strict application of the seismic code and the education of building professionals and rural masons to minimise national economic disaster, especially when it is certain that earthquakes will regularly strike (Chile, Peru).
F. Plans should be made to better register earthquakes and to better define the general seismic zoning and micro zoning, depending on the local soil conditions.
G. To upgrade and retrofit the existing large building stock to the level of the seismic code is a massive undertaking in labour and finances. This requires a phased programme and education of all rural masons and builders.
H. New low-cost methods of information sharing on seismic-resistant construction, which does not require the presence of civil servants, must be considered for rural housing. An option is an

integrated Q&A system with the accessibility of a variety of different building plans and Bills of Quantity complying with the seismic code per seismic zoning.

I. Most adobe, stone and non-cement mortar masoned brick buildings do not comply with the seismic code in the high-risk seismic zones. Seismic strengthening of such buildings constructed with heavy materials is seldom economic, even if the cost of labour is very low. Reconstruction and redesigning the lay-out creates stronger and more sustainable buildings. It can economise on heavy building materials as well.

In Nepal with an estimated population of 29 million inhabitants[yy] and an estimated family size of 4.5 persons[zz], 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.[16]

In Nepal the old building stock was not upgraded after the 1934 earthquake, while additional storeys may have been added without due consideration of seismic risk.

These buildings already existed in 1934, but now the top stories have collapsed.

Most of these buildings cannot be economically repaired.

The recent events show that it is insufficient to develop only detailed seismic engineering codes for new low- and high-rise buildings. Development of economic mechanisms to upgrade the existing building stock, not only in the main capital, but in the rural areas as well, is equally important.

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

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