SHOCK SAFE NEPAL

Team One

A.O. de Stoppelaar
A.J. Oosterhof
B.C. Can Düzgün
C.J. Spelt
E.C.M. van Wijnbergen

TU Delft DIMI Deltas, Infrastructures & Mobility Initiative
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Supervisor	CME coordinator	Drs.ir. J.G. (Jules) Verlaan
Academic board	grading professor	Prof.dr.ir. A.R.M. (Rogier) Wolfert
	IDM coordinator	Dr.ir. G.A. (Sander) van Nederveen
	BCC coordinator	Ir. H.R. (Roel) Schipper
	internship coordinator	Dr.ir. M.G.C. (Marian) Bosch-Rekveldt

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Deltas, Infrastructures & Mobility Initiative

Preface

In May 2015 Cas de Stoppelaar, the Consul General of Nepal to the Netherlands, pitched the problems in Nepal regarding earthquake engineering to the TU Delft. Jules Verlaan, the Master Program Director of Construction Management and Engineering (CME), and De Stoppelaar organized an initial kick-off meeting with interested parties.

During this meeting people with various expertise's and different backgrounds were invited; such as construction companies, TU Delft, and people with knowledge of Nepal and its business climate. In this meeting, where Baris Can Düzgün and Allard de Stoppelaar attended, the foundation was made to set up the students project 'Shock Safe Nepal'.

The student team was completed by including Arjan Oosterhof, Coen Spelt and Emilie van Wijnbergen. With the help of our supervisors, academic board and the Consul General our scope and purpose were defined. The project was set up under the Master course CIE4061-09 Multidisciplinary Project, in which an interfaculty team is required. The team consists of CME and Building Engineering students, with four different bachelor backgrounds.

The initial idea of Shock Safe Nepal is to create a knowledge platform by sending multiple student teams to Nepal, each team contributing to the platform. Team one's mission is a reconnaissance mission, in which we explore the possibilities for future Shock Safe Nepal projects. We want it to be a platform for (low-tech and non-engineered) earthquake proof building solutions with a long term vision.

4 September 2015 we left the Netherlands to spend two months in Kathmandu, Nepal. Cas de Stoppelaar joined the first two weeks to help start up the project, and introduce us to interesting parties.

This report consists of two reports: the first report is the basis for future teams, the second report goes more into depth on one of the research topics.

We wish the following Shock Safe Nepal teams lots of success.

A.O. (Allard) de Stoppelaar
A.J. (Arjan) Oosterhof
B.C. (Baris) Can Düzgün
C.J. (Coen) Spelt
E.C.M. (Emilie) van Wijnbergen

Delft, November 2015

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Abstract

Abstract report one

As a response to the 2015 Nepal earthquakes Shock Safe Nepal was founded to function as platform intended to contribute to the development of knowledge on earthquake safe housing. The goal of report one is to serve as a base that can be used and expanded by future Shock Safe Nepal groups. Literature study, field work and interviews have been performed resulting in main findings and products serving as an exploratory introduction on the context of Nepal.

The main findings regarding the context on Nepal's national level are firstly the country's dependency on India and China, the superpowers between which it is landlocked. Nepal is highly dependent on gas, petrol, electricity, and on monetary and physical foreign aid. Secondly, the diverse nature of Nepal is characterised by a huge variety of ethnicities, social classes, resources and materials ranging from the Himalayas (4 to 8.8 km's altitude), the middle mountains and valleys (1.5 to 4 km's) and the midlands to the Terai (0.06 to 1.5 km). Thirdly it's complex fabrics of politics, society and levels of social interaction. Fourthly the diversity of the built environment with corresponding building methods, characteristics and key earthquake related issues. Based on a settlement typology classification five zones are distinguished: 'Urban Core', 'Urban Villages', 'Urban Historical Settlements', 'Rural Villages' and 'Remote Villages'. Since more than a half million houses were destroyed during the quakes, a large task of rebuilding lies ahead. For this reason, an assessment is made of 19 possible building methods for rebuilding. These methods belong to one of three classes being, native or embedded, upcoming and potentially introducible. Field research was performed to make an overview of the earthquake related damage observed in the native building methods. Finally, the main principles on earthquake resistant building are collected and presented.
Based on the contextual characteristics of Nepal (gathered through field research, literature review and interviews) a comprehensive set of higher level requirements was set-up for rebuilding in Nepal. Within these requirements a distinction is made between fixed and variable aspects which are dependent on the settlement typological classification within which a building is intended to be built.

The main findings regarding the challenge of rebuilding are that much of the knowledge on earthquake safe constructions is already present in Nepal. The Nepal National Building code is developed (and at the moment of writing being updated) by foreign and Nepali engineers and contains most of the knowledge. An important conclusion with respect to rebuilding is that there is not necessarily a lack of knowledge on seismic engineering (in other words: on how to rebuild) but are mainly related to the implementation: how to transfer this technical building knowledge to local masons and ensure good execution.

Report one delivers three end products:
An overview of relevant contextual information for rebuilding of Nepal and a critical review of the developments after the earthquakes. An extensive overview is given of a selection of native, upcoming and potential building methods, evaluated by means of a comprehensive set of requirements for rebuilding which were set-up in the research. On the basis of this exploratory research, recommendations are given for further research on earthquake safe housing (for successive Shock Safe Nepal groups), including an overview of relevant stakeholders to take into account. The complete first report will serve as a basis for all Shock Safe Nepal groups, a starting point for new research, which will contribute to a safe long-term housing solution.

The recommendations for further research are supported by multiple SWOT-analysis throughout the report; provided insight regarding opportunities and threats. Concluding with a SWOT summary of all presented information relevant when rebuilding earthquake struck Nepal.

Abstract report two

In report one, relevant information is documented to form a base and a framework is set-up to evaluate suitable methods for rebuilding. In report two a case study was chosen to implement this framework: settlement zone D, rural villages. Within the settlement typology of rural villages, a specific challenge is assessed namely, constructions on slopes in ribbon developed settlements. Although it is definitely not recommended to build on sloped ground (for multiple structural and seismic related reasons) but due to scarcity of flat building sites it seems unavoidable that a lot of people will continue to build on slopes anyway. The goal of this research is to test the framework and assess the preferred post-earthquake reconstruction methods bound by the requirement aspects which correspond to Ribbon Developments. The set of requirements is organised by means of the following main aspects: technical, resources, feasibility, social-cultural, functional and sustainability.

First it is tested if the 19 potential building methods lie within the solution space (meaning: the satisfying the upper- and lower boundary conditions). Low strength stone and brick masonry, adobe, rammed earth, bamboo and earth bags building methods are excluded due to low scorings within the solution space. These methods were excluded due to insufficient performance on the following aspects: seismic performance, possibilities for expansion, accommodation for workplace, number of storeys possible, the amount and complexity of maintenance required or the lifespan. The remaining 13 building methods are ranked by a Multi Criteria Analysis and scenario analysis, resulting in a shortlist of suitable building methods for the rebuilding of the chosen case study situation. The four scenario's used are: baseline, no subsidy, subsidy, and full material availability. The shortlist of preferred building methods is: 'Reinforced Cement Concrete' frame structures, 'Steel' frame structures, 'Confined Masonry' and 'Stone Cement Masonry'. From this shortlist the 'Reinforced Cement Concrete' building method is chosen for further elaboration. The research is concluded by presenting conceptual design ideas for the chosen building method ('Reinforced Cement Concrete') and laying the foundation for further complementary research by following Shock Safe Nepal groups.

This conceptual design led to a number of findings related to the technical and functional demands such as the need for stabilization of the slope and the designing of a fitting foundation. An overview is made of the rebuilding challenges with respect to socio-economic/functional-, building-, natural hazard and structural challenges. Then, a design proposal is done with ideas on the levels of building organisation (building in blocks), lateral load resisting elements, and building appearance. A proposal is done for composite columns (fitted with H-beams) and shear walls to compensate for soft storeys. The coupling of building blocks can be used to create more bays, which provides more redundancy, greater resistance against lateral forces and possibilities to compensate for open storefronts. These proposals seem to address a lot of challenges, whereas they also create some new challenges. The organizational challenges corresponding to the proposed design are identified but left open for further research. The design chapter shows the potential of more elaborated research on a specific problem and acts as an invitation for future Shock Safe Nepal groups and their research.

Acknowledgements

We would like to thank a couple of organisations and people for guiding us in our project. Without this help we would not have been able to write these reports.

First of all we would like to thank Cas de Stoppelaar for preparing us for our adventure and guiding us during our first weeks in Nepal. We thank Drs. ir. Jules Verlaan, Dr. ir. Roel Schippers, Prof. Dr. ir. Rogier Wolfert, Dr. ir. Sander van Nederveen, Dr. ir. Marian Bosch-Rekveldt for guidance and supervising at Delft University of Technology. We would like to thank Martijn Schildkamp, Ram Budhathoki, Fanindra Panta and others in preparing us in our research by sharing knowledge on Nepal and the Nepalese construction industry.

Besides support from The Netherlands we also had the pleasure of receiving help from within Nepal. We would like to thank Padma Sunder Joshi and others from UN-Habitat, Siobhan Kennedy from Shelter Cluster, Surya Narayan and others from NSET, Anil Tuladhar, Kusma Thapa, and Anatta Shresthacharya. A special thanks goes out to Jolein Feteris and Jan-Kees van Mourik for providing us office space in the Drafting Factory.

Last but not least we would like to thank DIMI, UfD-TBI, FIS fonds, Rotary Sliedrecht and our crowdfunders for their financial support.

Report One

“Assessment of context on national level”

1. Introduction

The recent earthquakes (April 25th and May 12th of 2015) with magnitudes of 7.6 and 6.8 on the scale of Richter and the following aftershocks have left a trail of destruction across the built environment of Nepal. The earthquakes affected 31 of the country's 75 districts, out of which 14 were diagnosed as 'crisis hit', as shown in figure 1.1. (National Planning Commission, 2015). Historic parts of the capital Kathmandu and villages in and around the Kathmandu valley are in ruins and many families are left homeless. According to the latest 'Post Disaster Needs Assessment' (N. P. C. Nepal, 2015b) there are 8,790 casualties and 22,300 injured. Numerous NGO's and charity organisations have jumped to their aid and have built short term shelters for the earthquake victims. However a long term solution remains. The challenge of rebuilding Nepal in an earthquake proof manner has many possible solutions. While these solutions are possible in theory not all are feasible, realistic, practical, fitting or structurally earthquake safe. To be able to assess which solutions (designs) are fit for rebuilding in a certain types of village in Nepal, research is needed.

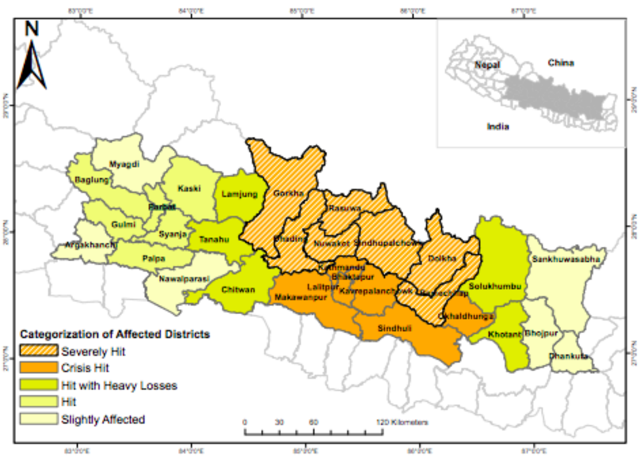


Figure 1.1. Categories of earthquake affected districts (National Planning Commission, 2015).

Shock Safe Nepal Vision and Mission

After the 2015 Nepal earthquakes and the subsequent aftershocks the Shock Safe Nepal project was initiated with the idea of working towards solutions and expanding practical knowledge regarding earthquake safe housing. Shock Safe Nepal is a continuous MSc student project set within a multidisciplinary (interfaculty) and international context. Shock Safe Nepal is envisioned to be multi phased with each phase being executed by a new team of TU Delft MSc students with their own specific focus, working towards a higher goal. The goal of the entire multiphase project is twofold and can be described as follows:

1. Shock Safe Nepal has envisioned itself to contribute to the knowledge and organization needed to reconstruct the +- 500,000 houses and retrofitting/repairing +- 250,000 houses, as determined in the PDNA (N. P. C. Nepal, 2015a). SSN wants to contribute to knowledge development on earthquake-proof building with respect to traditional and culturally accepted building methods, and realize a platform that future student groups can use to base their own Shock Safe Nepal research on.

2. Since the earthquake incidents in Groningen the TU Delft is focusing more on earthquake related research and education. Shock Safe Nepal creates the opportunity for a continuing TU Delft research project on earthquake-proof building, offers possibilities for cooperation with Nepali Universities and enables the TU Delft to become an international knowledge centre for earthquake engineering.

Goal of Report One: Reconnaissance

In order for future Shock Safe Nepal teams to be able to achieve the higher goals information is needed that serves as a foundation for following researches. This need for information forms a base for the first report of Shock Safe Nepal that should function as an introduction into rebuilding Nepal. Ideally each team should validate the variable elements of this report and should add any changes or new information that is lacking.

2. Methodology

Report one is intended to be the introduction for rebuilding Nepal, it is the foundation for future research containing an introduction on all issues and facts relevant to building in Nepal. This document will not be set up as a research but rather as an inventory of all relevant information or an extensive analysis of all present information.

This foundation is created by informing the reader about the context, relevant building methods, areal classification, earthquake damages, earthquake principles, characteristic challenges and by the creation of a framework for the assessment of building methods.

Firstly an assessment of the context will be made on national level focusing on the reconstruction of Nepal. This will be done by addressing several topics which are of importance when designing a housing project. The topics will be elaborated on by means of literature reviews, fieldwork, interviews, meetings and market research. To introduce the information a general introduction on Nepal and its institutional history will be given. To understand the physical housing demands the geographical and climatological characteristics will be looked into. Often construction is a sector which is heavily influenced by national governance, politics and the economy, making this information relevant in the process of reconstruction. When the boundaries of continents but also countries get crossed another aspect is of importance namely, the cross-cultural differences. These differences have large impacts on many aspects (e.g. social structures), these aspects and their consequences will be analyzed by use of the theory of (Hofstede). Obviously when the focuses is laid on construction an analysis is needed of the construction market and industry including the financial aspects. And concluding with an overview of important stakeholders that play a role when addressing the issue of reconstruction.

Secondly an initial selection of building methods needs to be made based on some higher-level requirements. The building methods that fall within the initial scope will partially be based on the intended views of Shock Safe Nepal team 1. These building methods are categorized on their embeddedness and need to be elaborated based on comparable aspects by means of literature reviews and fieldwork. The documentation of building methods will be a 'live' document that needs to be complemented with new building methods and new information on already incorporated building methods.

The settlements in different areas of the country will have different demands and requirements for the designing of houses. The differences can be related to geographical, ethnical and built environment characteristics, these will be used in the classification of areas that have similar challenges. These classifications will be elaborated on with a photo report, general characteristics, and the present building methods, a global damage assessment, a SWOT and specific challenges that can be used for further research.

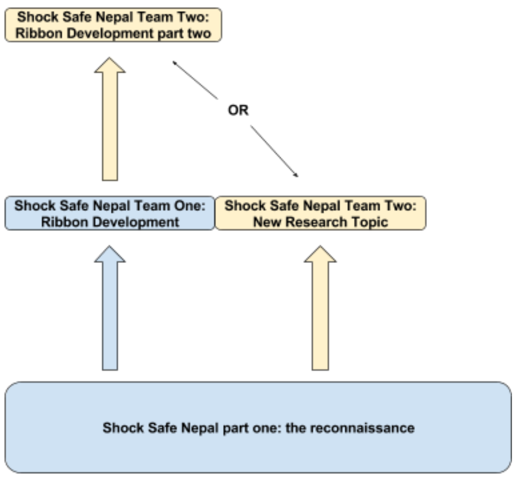


Figure 2.1. Set up of Shock Safe Nepal (Shock Safe Nepal group 1).

All information regarding the context assessment, settlement types and building methods will be used for the defining of a framework for assessing building methods by means of higher-level requirements. Part one will assist in the selection of building methods based on the possible and desirable solutions for reconstruction in Nepal. Future Shock Safe Nepal teams will continue this research and expand the information package.

3. The context of Nepal

3.1. General introduction of Nepal

The Federal Democratic Republic of Nepal is a South Asian country that is located in the Himalayas and home to many of the world's highest mountains. It is landlocked between the people's republic of China in the North and India in the South, East and West borders of Nepal. Despite that Nepal is a relatively small country (Mapfight) it has a great diversity regarding ethnic groups, nature and climatic conditions. Its many rivers that run from North to South divide the country. The division by the rivers has affected the diversity of ethnic groups creating many different sub-groups and over 90 different languages and dialects. A great contrast exists between its countryside where nature is in charge and culture is at its purest, and its bigger cities and capital where tourism and economic welfare have taken an overhand. The bordering countries have had an influence on the religions in Nepal and have led to the two major religions Hinduism and Buddhism to go hand in hand with an inspiring religious tolerance.

Figure 3.1. Nepal is landlocked between China and India (Geology.com, 2015).

Figure 3.2. Nepal on the world map (Little-bells, 2014).

3.2. Geographical characteristics

Altitude and climate

The country has unique geographical characteristics such as the great altitude variations (from +60 mean sea level to +8,848 mean sea level within a stretch of 150 kilometres) affecting the climate conditions that differ from arctic to subtropical. From North to South Nepal the geography changes from the higher Himalayas with its rocky and icy peaks to the lower Himalayas and high mountains and valleys with their more fertile soils of earth and clay, and the lower flat (Terai) regions with their subtropical forests and humid weather. (Worldatlas)

Natural resources

Nepal's biggest natural resources are tourism and hydroelectricity. Both have to do with the Himalayas that is are a big part of Nepal. The hydropower currently is not enough to provide Nepal of enough energy. Large possibilities lie here for Nepal.

Nepal has various other natural resources such as copper, iron, mica and limestone. Nevertheless due to the difficult and steep mountain terrain the exploitation of these resources is very hard.

Moreover Nepal has a lot of forest. Yet due to overpopulation the 'carrying capacity' is not enough for the middle hill areas. Most of the forest is protected which makes it hard to get wood from (UNEP, 2011).

This causes that Nepal only exports for 894 million and imports for 6.42 billion, resulting in a negative trade balance of $5.53 billion in 2013. Most of this import crosses the border with India (OEC).

Seismic hazard

Nepal borders the boundary between the seismically active Indian and Eurasian plates. The Indian plate is moving in Northern direction, sliding underneath the Eurasian plate at a remarkably high rate of 40-50 mm per year (USGS National Earthquake Information Center). The mountainous region of the Himalaya and the Tibetan Plateau are the surface expression of the collision of these plates. The converging of the plates causes a build-up of tectonic stresses, and an accumulation of strain, making the region a high seismic active area. Multiple earthquakes affected the area. Large and devastating earthquakes (with intensity of X out of XII of the Mercalli scale) tend to occur in a cycle of 75-100 years (Pradhan, 2000). The Kathmandu valley was originally a lake. The clay ground causes amplifications of the earthquake motions (Pradhan, 2000).

Large earthquakes have occurred in 1253, 1407, 1681, 1803, 1824, 1833 and 1835. In the 20th century a major earthquake ('the Great Bihar') occurred in 1934, with magnitude 8.4 in Richter scale. In 1988 an earthquake with Richter scale 6.6 occurred in Udayapur, the east of Nepal. Recently a severe earthquake series occurred in April-May of 2015. The first earthquake occurred on 25 April 2015, with an epicentre located in Barpak in the Gorkha district. The 'Ghorka' earthquake with a Richter scale of 7.8 Mw (Intensity of IX on Mercalli scale), was followed up by an aftershock of 7.3Mw. The second earthquake occurred on 12 may 2015 with an epicentre located at the border of Dolakha and Sindupalchowk, with a Richter scale of 7.3 Mw, followed by an aftershock of 5.7 Mw (USGS National Earthquake Information Center, 2015b) (USGS National Earthquake Information Center, 2015a).

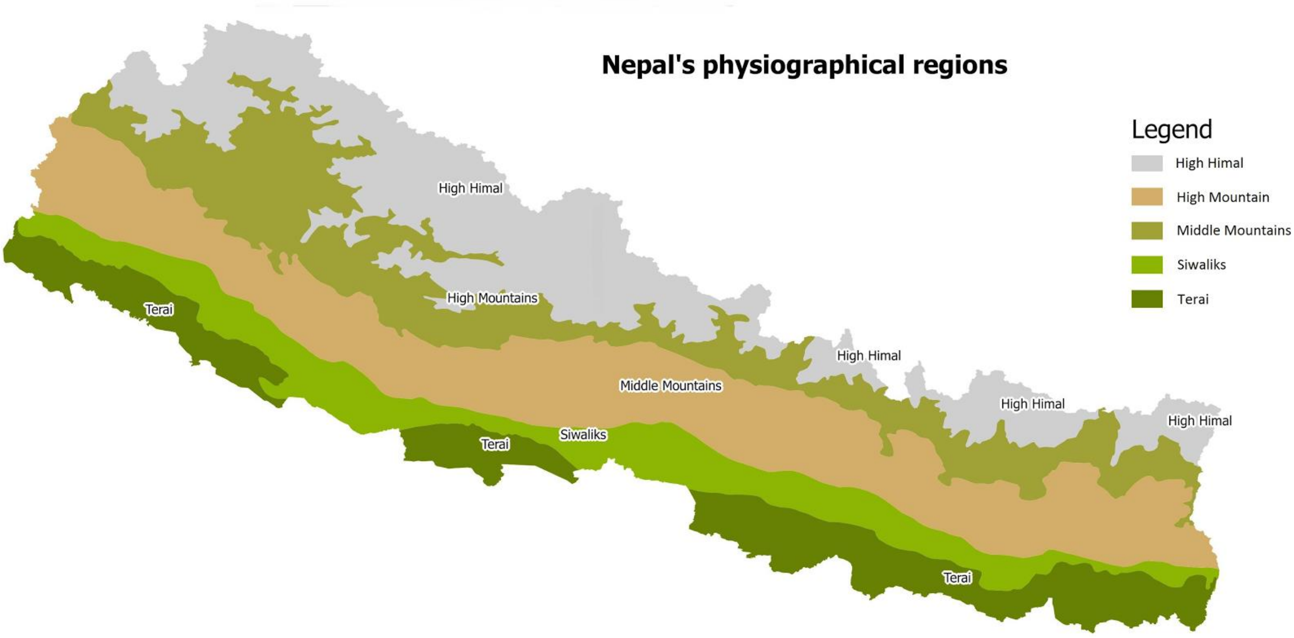


Figure 3.3. Nepal's physiographical regions (UMN, 2014).

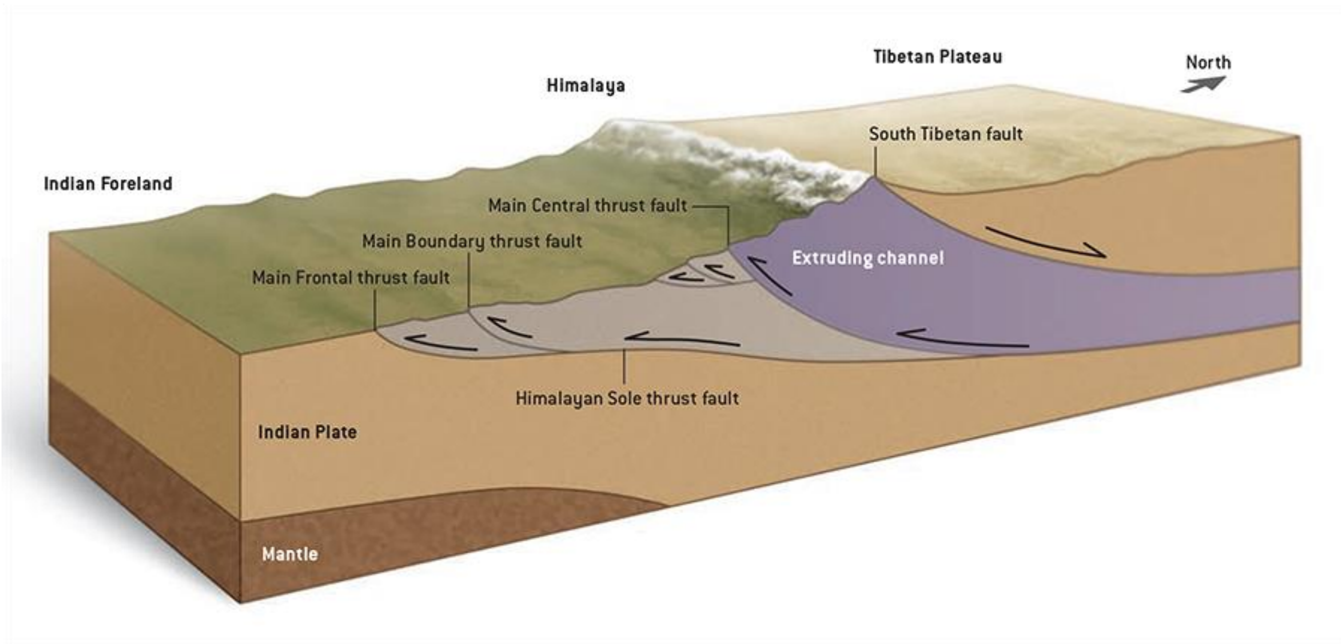


Figure 3.4. Nepal Geographically (American, 2006).

3.3. Climate related

Construction in Nepal is season bound. The best time to start gathering the materials for construction is from December to January, the start of construction is best in the month of February because of the availability of raw materials, work efficiency/quality and skilled labour. Roughly the climate can be divided into four main seasons:

June-September:

Rainy season. Inappropriate to start construction because of the heavy rain. The disturbance of the monsoon will lead to more difficulties during construction, which can result in extra cost for house owners. During the period most of the agricultural work is done meaning less availability of construction workers.

October-December:

Clear and Cool, the rainy season has stopped and main season for the tourist to visit Nepal. Also the best time to start with the preparations for construction.

January-March:

The cold but dry season with temperatures around 10 degrees, the appropriate time to start construction. Although during the period increased power cuts and shorter amount of daylight create additional problems.

April-June:

End of the dry season and start rainy season, during the period the weather conditions are not fixed and construction could expect a short periods of heavy rainfall (Housingnepal, 2013).

According to the Department of Urban Development and Building Construction (DUDBC) the cost of construction differs by 15 to 20 percent, depending on the period when construction is started. It is seen that 60 percent of the houses are constructed in the months February and March. This is done because the weather conditions are most ideal during that period but also because people want to acquire new property after the main festival season (DUDBC, 2015). As in all over the world the seasons shift, during our trip we still experienced short heavy rainfall in the end of September/ beginning of October, meaning that the best time to start construction also shift further back during the year.

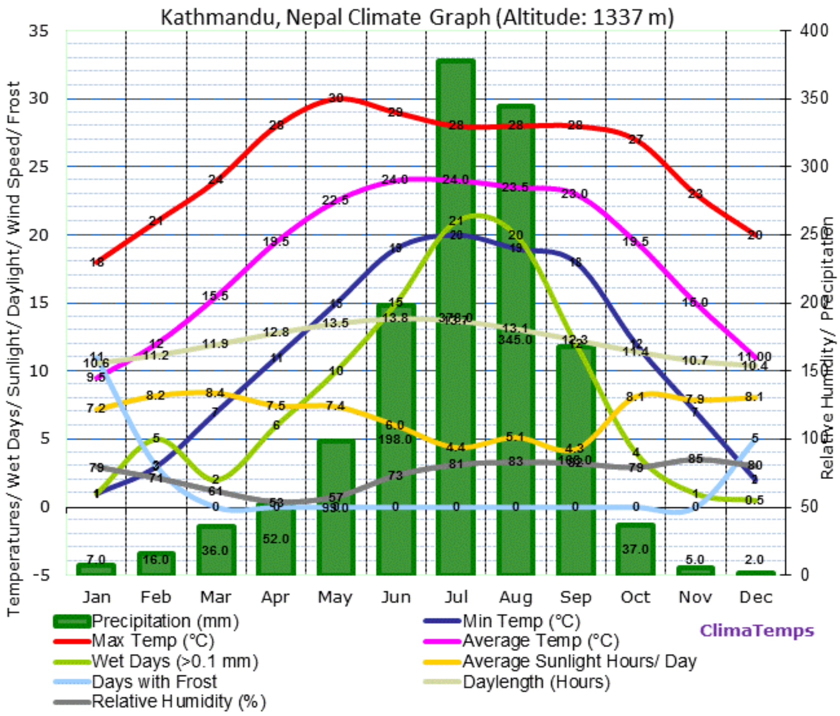


Figure 3.5. Kathmandu climate graph (Climatemps, 2014).

3.4 Institutional historical of Nepal

The first human establishments in Nepal were founded in the Kathmandu Valley with its fertile clay soils. The Nepali rulers often consisted of different kingdoms that had their own territory with either a background in Buddhism or Hinduism, with its climax in the 12th century that was marked by the presence of three large kingdoms that reigned for successive periods. The Malla kings started their reign from the 12th century leading to the geometry of the current Nepal. In 1768 the unified Kingdom of Nepal was formed by King Prithvi Narayan Shah (Please, 2015).

For the past centuries the Shah dynasty ruled the *Kingdom* of Nepal (with the exception of the so called Rana rule from the mid-19th century till 1951 when the king was kept silent) (Hagen, 1980). Basically Nepal knew only one centre of power, namely 'His Majesty'. The king was surrounded with all kinds of vassals, like the various layers of an onion. If you wanted to achieve something, you had to go to the king through all these layers of middlemen.

The king off course had the power to lend someone a favour, in return for some kind of benignity. In principle money would go up to the King while the favours would go out. While this system seems very corrupt, Nepali wouldn't address this as corruption – the terminology corruption doesn't exist in the same context like we know it in the Netherlands (Gerzon, 2014).

However there came an end to the Shah dynasty after a long struggle for a parliamentary democracy in 2008; the king lost all his powers (Ramesh, 2008). After his resignation there came a parliament that again does not function, as it should. For example since 2008 there has not been an agreement for the constitution of Nepal till 2015 (Stoppelaar, 2014).

What happened in reality is that there isn't one centre of power anymore but a lot of different ministries, all with their own centre. This causes a complicated situation. Procedures do not follow the lines as they should and knowledge about the system and people are sometimes more important than rules (Worldbank, 2014).

3.5 Politics

In 2008 the Nepalese Constituent Assembly abolished the monarchy and created a republic with a multi-party system: The president is the head of state and the prime minister is the head of government. The legislative power is vested in the Constituent Assembly, a body of 601 members that serve as Nepal's parliament.

Around the period of the big 2015 earthquakes the main task of the Constituent Assembly was drafting a new constitution, which was a difficult process due to disagreements between governmental parties. After the earthquake the prime minister used his mandate to promote a Central Natural Disaster Relief Committee (CNDRC) now called the National Planning Commission (NPC). This commission had the authority and resources to act quickly and offer relief support.

Delayed plans for rebuilding and the building code

The political situation in Nepal around the time of the 2015 earthquakes was very unstable and was one of the reasons why the reconstruction process is very slow. As laid down by the constitution the prime minister's mandate only lasted for 60 days. During these 60 days the parliament failed to approve the rebuilding committee causing the mandate to expire. Resulting in a delay for the rebuilding plans and building code of Nepal. Many people were promised a fund with the side note that the constructed building had to be according to the new plans for earthquake safe housing. The delay of these plans led to people needing to wait before being able to rebuild while the wintertime was approaching.

Structural challenges concerning, water, gas, electricity and petrol

Next to the incidental events related to politics Nepal also suffers from more structural challenges that make everyday life slightly different than in other countries. Due to its geographical location and presence of natural resources, Nepal is dependent on its neighbouring countries for its fuels (Petrol, Gas and Electricity). The lack of infrastructure for utilities require for average households to have all gas powered units connected to a small gas tank and all units that require water to be connected to water tanks (in urban areas water is available from the net, however it is not drinkable for everybody). The water to refill the tanks is abstracted from water springs in Nepal while the gas is imported from India. Both of these substances need to be transported to central locations or household in Nepal requiring trucks and other motorized vehicles.

Concerning electricity Nepal struggles with three different problems that amplify each other. The generation capacity of power during peak hours is too low to cope with the demand. The transmission networks are inefficient and inadequate at transporting the energy from production units to distribution units. Finally the distribution is inefficient and inadequate resulting in the available capacity to be distributed among the many demanders by means load shedding, at times provide no more than 8 hours of electricity per day per household. (Asian Development Bank). The remaining hour's energy is produced individually by means of generators running on petrol or diesel.

The above mentioned challenges create another challenge altogether, the need for gas and water transported by trucks and the production of electricity by means of generators are all dependent on the availability of petrol, another fuel that is not produced in Nepal. Thus in the situation that petrol is unavailable it affects the availability of water for drinking and other purposes, the availability of gas for heating of water and cooking, and the ability to produce one's own electricity. This results in power only being available when load shedding is not active in a particular group.

The unavailability of these resources, the fact that Nepal is landlocked and that politics are distracted by other issues leads to structural dependencies on its neighbouring countries, which can be a threat in case of political instability in the relation with one of the neighbouring countries.

3.6 Nepalese Economy

Nepal is considered as one of the least developed countries in the world. According to the Worldbank out of the total population of 30 million, 25.2% lives below the national poverty line. In 2014 Nepal had a GDP of $19.64 billion this is only a fraction of the $869.5 billion the GDP of The Netherlands. (Worldbank, 2014) The fact that Nepal is landlocked between India and China creates additional challenges in achieving economic growth. Combined with the on-going power shortages and underdeveloped transportation infrastructure Nepal still manages to get an estimated 4,5% GDP growth in 2016. (CIA, 2015). The GNI per capita is used get an understanding of the average salaries; in Nepal the GNI per capita is $730. Nepal is for almost 25% dependable on remittances by foreign governments. The largest part of Nepal's GDP comes out of agriculture, accountable for the livelihood of 70% of the population; the industrial activities mainly focus on the processing of agricultural products. In the peak seasons the tourism sector is also accountable for a large part of the occupation of the population, unfortunately this has halted after the earthquake. Nepal has a lot of potential to gain income from hydropower, but the lack of political continuity and proneness to natural disaster has hampered foreign investments to get the projects started (OEC, 2015).

The earthquakes had a big impact on the economic situation of Nepal, according to the PDNA an additional 2.5 to 3.5 percent of the population will be pushed into poverty, equivalent to at least 700.000 additional poor. The PDNA made an estimation to quantify the total damage and losses, the total damages are estimated to be $5 billion, the total losses are estimated to be $1,8 billion. (N. P. C. Nepal, 2015b) The housing sector was affected most, with the total effects valued at 350 million NPR. These total effects exist out of damaged and losses, total damaged is defined as the combined cost to replace the destroyed house, repair cost of partially damaged house and replacement cost of household goods. The total losses are the combined cost of demolition and clearing and transitional shelter. (N. P. C. Nepal, 2015b)

3.7 Cross-cultural differences

Since the Dutch and Nepalese culture seems to be very different we analysed cultural differences. These differences are aspects to take into account when interviewing and working in Nepal. As a theoretical framework the six cultural dimensions of the Hofstede Centre are used to provide the cultural aspects of our project. Since these dimensions are renowned and describe the national dimensions, distinguishing countries rather than individuals.

The Power Distance Index:

This index shows in what way people perceive power differences. A high rate means people expect that power is distributed unequally, autocratic and paternalistic. People will accept power simply based on the hierarchical position. Lower rated countries show that people expect power relations are more consultative and/or democratic. Formal positions are less important and people expect more to be treated like an equal, regardless of the hierarchical position (Hofstede, 2015)

The relatively high score of 65 on the power distance index means people in Nepal accept a hierarchical system more than we do in The Netherlands. Even though the caste system of Nepal has been abolished in 1963 it still remains a fundamental aspect of how people perceive hierarchy (Feller, 2008, p. 41).

Own experience: We have learned to ask open questions instead of 'yes or no questions'. Nepali tend to answer all questions with yes in order not to disappoint you. Even though according to the caste system we are considered to be part of the fourth layer, a lot of Nepalese people treat us (an unnecessary amount) of respect. Often it is hard to connect with a Nepali, the power distance avoids this. Also we've noticed the power distance between higher and lower layers of society. Nepal has a big gap between rich and poor, we have seen people act like this as well.

Individualism versus Collectivism:

This dimension shows to what degree individuals are integrated to groups. In collectivistic societies people are more loyal to another in exchange for protection, people act as members of a lifelong group. Individualistic societies are more focussed on personal achievements and individual rights (Hofstede, 2015).

This dimension displays the biggest difference in known Hofstede dimensions of Nepal and the Netherlands. Nepal is a collectivistic country compared to The Netherlands.

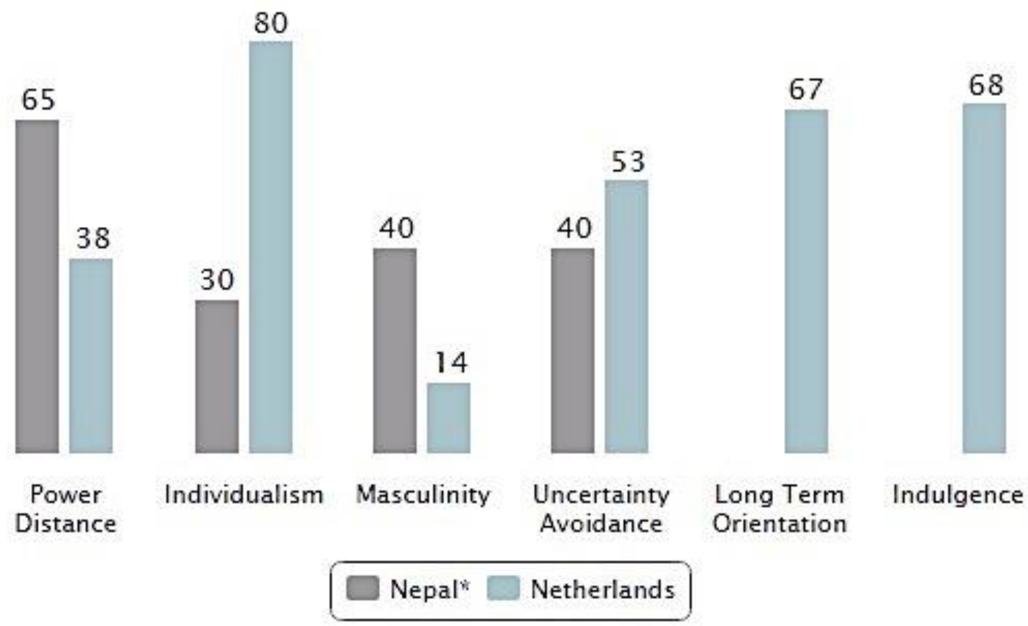


Figure 3.6.: cultural differences Nepal - The Netherlands (Hofstede).

Own experience: Nepali use public places much more collectivistic than we do in The Netherlands. Entire families wash themselves and their clothes in fountains and swimming pools. Temples are gathering places for all layers of society.

Masculinity versus Femininity

Displays the differences between masculine and feminine cultures. Masculine values are competitiveness, assertiveness, materialism, ambition and power. Feminine values are focussed on relationships and quality of life, such as cooperation, modesty, caring for the weak and quality of life (Hofstede).

The Netherlands is considered to be a very feminine society meaning caring for others and zqualities of life are important values. Nepali however strive more to be the best instead of liking what you do. With a score of 40 it still is a feminine society but leaning towards masculine, meaning competition, achievement and success are important values as well.

Own experience: the feminine character of the Nepalese is noticeable in their interaction with each other. People seem to care for each other and their quality of life. Besides that Nepalese seem very modest, sometimes unwilling to accept compliments or gifts.

Uncertainty Avoidance Index:

Gives the degree in which people tolerate the uncertainty of their environment. People in low UAI cultures are comfortable with unstructured or changeable environments; high numbers of rules are not necessary. People who live in high UAI cultures need rules, laws and regulations to control the uncertainty factor (Hofstede).

Even though the Netherlands and Nepal are comparable, Nepal tends to be less uncertainty avoidant. People are fairly relaxed and not unwilling to taking risks. Symptoms are people are not aggressive and emotions are not shown often. Besides that a majority believes in Karma which revolves around acceptance of fate. This could lead to Nepalese shrugging their shoulders during difficult situations (Feller, 2008, pp. 40-41).

Own experience: Nepali seems very relaxed and non-violent. In traffic they do not get agitated easily despite the chaotic driving style in Kathmandu. Also in combination with the Hindu and Buddhist religion people seem to embrace fate, not worrying too much about uncertainties.
Information on the dimensions Long Term Orientation and Indulgence are missing at the Hofstede centre. In order to get an idea on these dimensions we will carefully make a comparison with India instead. Due to the fact South Nepal is similar to North India, but North Nepal is only comparable to Tibet, it is more likely to presume India fits the Nepalese profile than China does. The following two dimensions are assumptions and therefore in the report cannot be used as facts.

Long Term versus Short Term Orientation

This dimension shows the different perception of the future and past/present. Long term-oriented societies focus more on the future what can be seen in its orientation towards rewards, persistence, saving and capacity for adaption. Short term oriented societies values are steadiness, respect for tradition, preservation and fulfilling social obligations (Hofstede).

India has an average score of 51 compared to 67 of The Netherlands. Out of own experience we think Nepal scores lower than Nepal, since respect for tradition and social obligations are important values in Nepal. Therefore Nepal is a short-term orientated country, which is noticeable working here.

Indulgence versus Restraint

Indulgent societies allow people to gratify their needs of basic and human desires related to enjoying life and having fun. Restraint societies have the idea that this gratification needs to be regulated by strict norms. In the restraint societies status is of importance, people expect materialistic reward for good jobs and easily feel treated unfair (Hofstede).

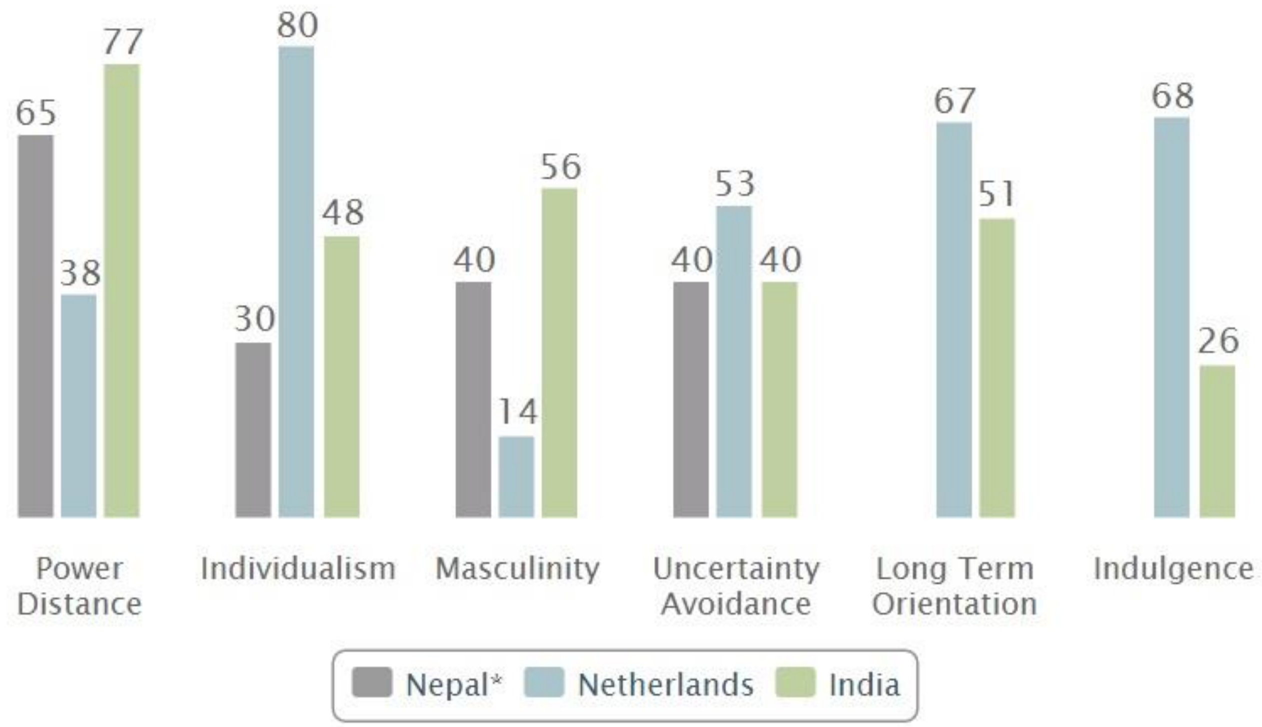


Figure 3.7. Nepal - The Netherlands – India (Hofstede).

India is a restraint society, which seems to fit the Nepalese context as well. However Nepalese do not seem to feel treated unfairly quickly, which could have something to do with their Hindu religion in which karma is of course an important value.

3.8 Social aspects

National Identity

Despite the fact Nepal has many different ethnic groups and differences in cultural detail there still is a strong national identity that focusses around the sacred Buddhist and Hindu sites which attract many tourists and the spectacular natural sights such as the Himalayan mountains and rivers.

Education

Education is one of the focus points of the Nepali government, although the government spends almost 14% of its budget on education the educational system was left shattered after the earthquake. According to Unicef almost one million children were enrolled in school before the earthquake, now there is no place to return for many children. The national education department indicates more than 5000 schools were damaged and 1000 schools were collapsed. Also before the earthquake schools had to deal with a high dropout rate: about 1.2 million children between the ages of 5 and 16 were dropping out or never attended school (Unicef, 2015).

Health

According to the standards of the UN the health situation of the population in Nepal is poor. This state of health is a result of the lack of drinking water, sanitation, food supplies and scarcity of medicine. The rapid growing population is especially placing stress on the available water resources (Kharel, Dhakal, & Poudyal, 2014) All these factors combined give a life expectancy of 68 years according, which is high for countries with comparable income and even higher than south Asia’s average (Worldbank, 2014).

Poverty

Nepal is the poorest country in South Asia, over the last decades the country has made progress reducing the poverty but is still falling behind. There is a large difference between the cities and the rural area, urban poverty lies around 10% of the population and rural poverty around 35%. In

2013 only 17% of the population lived in urban areas, but Nepal is urbanizing rapidly: the Kathmandu Valley with a population of 2,5 million is growing at 4% per year. The fastest growing settlements are actually the towns along the main highways, with population increasing by 5-7 percent every year (Worldbank, 2013).

Labour and labour division

Traditionally labour in Nepal was determined by social status and caste with the lower castes holding the occupations that are physically the heaviest and most unclean. Among genders there is also a division of labour, even though both genders perform physically heavy work "Men perform the heavier agricultural tasks and often engage in trade, pottering, and other work outside the village" while woman "cook, care for children, wash clothes, and collect firewood and fodder". Often work is a family business where older people, parents and children each have their own roll. Examples that can be seen all over Nepal are, at the construction site the men do the constructing while woman and children prepare or carry materials needed for the construction (bricks, breaking rocks etc.). And at a family shop, the man of the house does the trading and buying of the inventory, the children work in the shop with the woman of the house carrying the final responsibility (Culture, 2015).

Family

In (Hindu) Nepali society the family consists out of the direct family, the extended family and relatives. People refer to each other as brother or sister even though they might not be related in that manner. This expanded use of the term family also has effect on the composition of households. Typically grandparents, parents, children, daughters-in-law and grandchildren all live in the same house, with the elders having more authority than the young. A household and resources are owned and shared by all family members and managed by the man of the house. Marriage is an important aspect in the creation of social bonds, and is often arranged by the elders of the family. When a son marries a woman, generally she moves into the household and falls in the lowest position until she gives birth to a child. This household set-up emphasises the importance of loyalty and solidarity over individualism. In more modern and wealthy families it is seen that children are also sent abroad for studies with only the eldest son being forced to return home to take care of the family. When the man of the house comes of age the possessions are split into equal portions and inherited by the sons. A consequence of this can be seen in villages where a house belonging to a father is divided over three sons. The welfare and household size of each son would differ causing the house to be expanded unequally according to the needs of each individual son (Culture, 2015).

Social structures within society

Next to the family that takes care of each other, a community (determined by caste, occupation, relatedness etc.) also has a role in society. It is often seen that private houses or courtyards are used by a certain community for group activities such as praying, singing, parties, workshops etc. etc. An example of this is the local pottery shop also being the gathering place for elderly (Culture, 2015).

3.9 Ethnic aspects

Until 2006 Nepal was the only Hindu Kingdom in the world, however Hindus (80,6%), Buddhists (10,7%), Muslims (4,2%) and others (4,5%) live together in peace for years due to the mutual respect and religious tolerance (Feller). The northern part of Nepal is considered to be more Buddhist and focussed on Tibet, while the south ethnical groups lean towards India. This north-south segregation is noticeable as well in the elevation of the country, also isolating some groups.

Due to main rivers flowing north-south from the Himalaya towards India, the valleys also created an east-west orientated segregation, which is noticeable in the ancient races map. These aspects resulted in Nepal having multiple ethnic groups with their own culture and language. The Kathmandu valley is primarily Newari, as can be seen in figure 3.9.

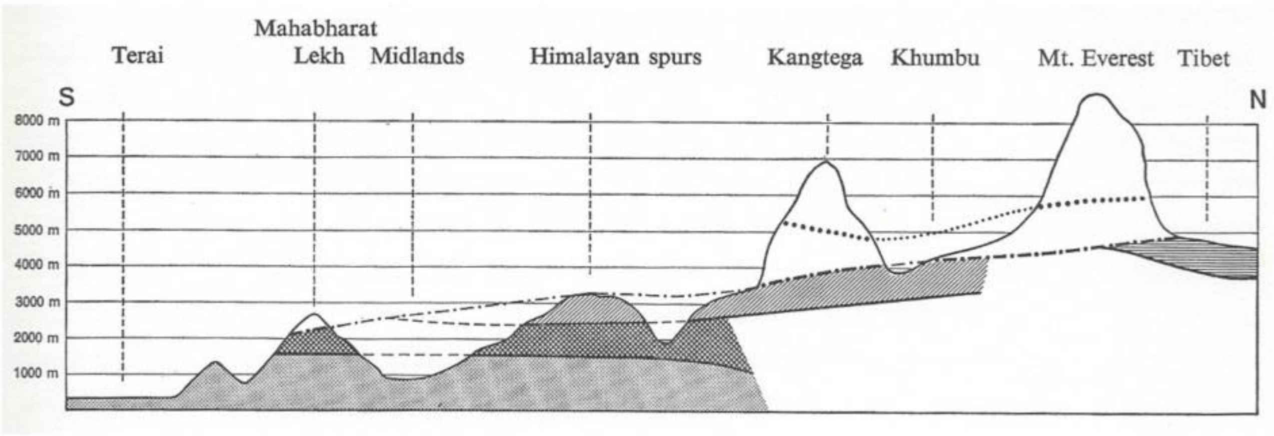


Figure 3.8. North-South segregation due to elevation (Hagen, 1980)

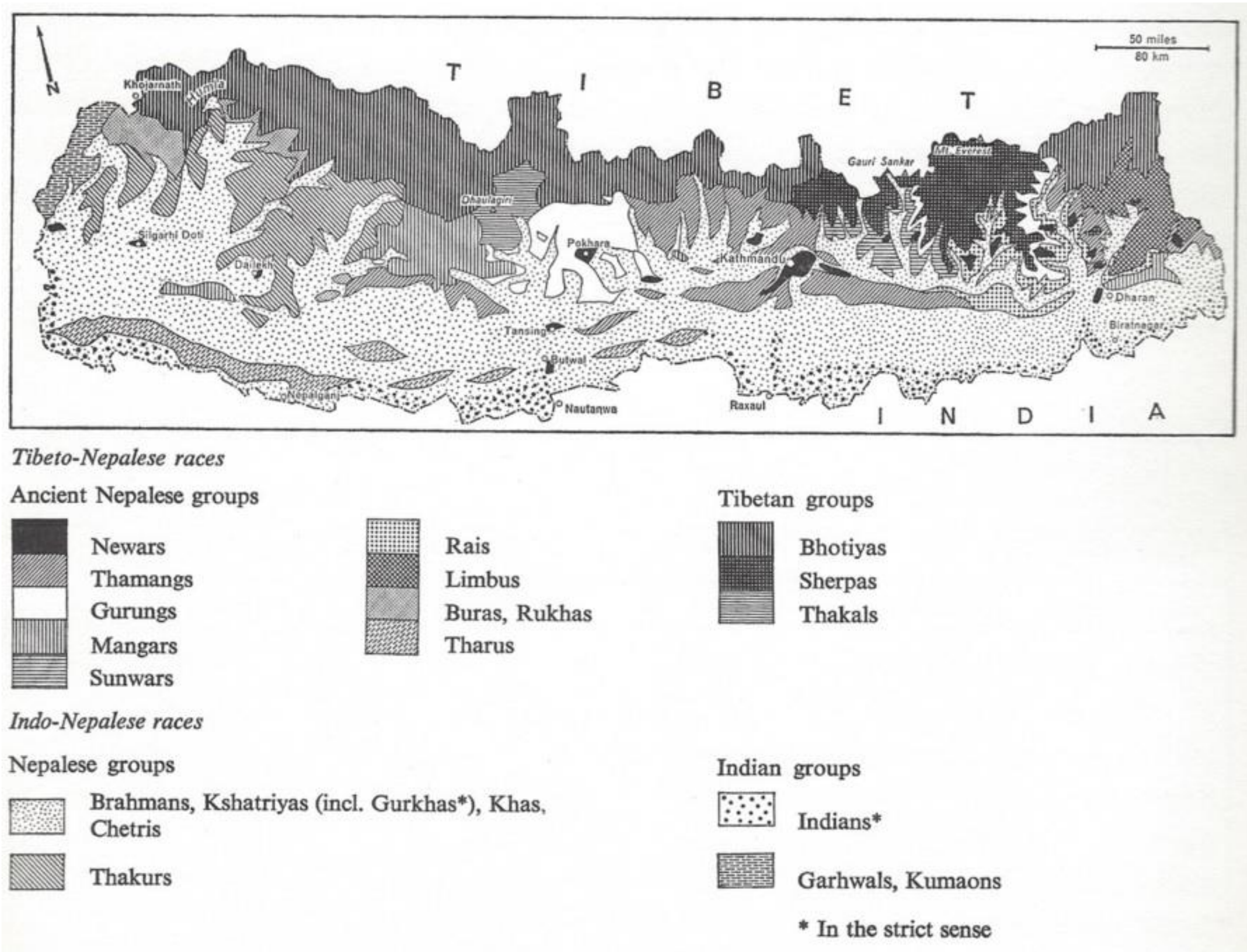


Figure 3.9. Ancient ethnic groups (Hagen, 1980).

Besides the ethnic division of society Nepal also still deals with the caste system, even though it officially has been abolished. The caste system, which is comparable to India's, classifies people on whether they are pure or impure. Even though a 1962 law made it illegal to discriminate against other castes, people can still treat each other differently based on their caste. Because of the aforementioned isolated ness of the parts of the country the interpretation of the caste system is different throughout Nepal. In general the caste system is generalised in table 3.1.

#	*Caste*	*Groups*	*Profession*
A. Pure *(water acceptable)*			
1	Tagadhari (Wearers of the sacred thread)	Upper caste Brahmans, Chhetris, Madhesi, Newar	Priests
2	Namasinya Matwali (non-enslavable alcohol drinkers)	Gurung, Magar, Sunuwar, Thakali, Rai, Limbu, Newar	Kings and warriors
3	Masinya Matwali (enslavable alcohol drinkers)	Bhote, Chepang, Gharti, Hayu, Kumal, Tharu	Traders and businessmen
B. Impure *(water unacceptable)*			
4	Pani Na Chaine (touchable)	Dhobi, Kasai, Kusale, Kulu, Musalman, Mlechha (foreigners)	Peasants and laborers
5	Achut (untouchable)	Badi, Damai, Gaine, Kadara, Kami, Sarki, Chyame, Pode	

Table 3.1. Nepal caste system adapted from (Bennet, Dahal, & Govindasamy, 2008).

3.10 Important stakeholders

For reconstructing Nepal several stakeholders are of importance for its process. The following stakeholders we've encountered during our project will be summarized and by a stakeholder identification map and a power-interest grid (Bryson, 2004). The following overview is not complete but illustrates the most relevant stakeholders during our project, future teams can complete this overview. In reality hundreds of parties are involved in reconstructing Nepal whether large scale or small scale like NGO's building a school. Depending on the phase of the reconstruction of Nepal presence and relevance of stakeholders can change.

Department of Urban Development and Building Construction (DUDBC): This government department has the function to formulate, plan and implement housing plans and urban and housing policies. Besides that it is responsible for designing, constructing, repairing and maintaining of government buildings. The objectives can be divided into three divisions (DUDBC, 2015):

1. Housing division.
   Promote safe and affordable housing through development of planned settlements
2. Building construction division
   Promote construction and development of safer, economical, and environmentally friendly buildings that also foster local architecture
3. Urban development division
   Promote sustainable urban development and urban rural linkages through development of modern physical facilities and conservation of cultural, religious, and historical heritage sites

Since promotion seems to be their biggest responsibility, they've for instance joined the Recovery and Reconstruction Working Group in which they propose standardized housing typologies. The DUDBC is now (in cooperation with international experts) rewriting the 1994 Building Codes.

National Planning Commission (NPC): The NPC is the advisory body of the Nepalese Government for national vision, planning and policy development. After the earthquakes they were assigned to perform the Post Disaster Needs Assessment (PDNA), in which the damage and needs are inventoried.

The Global Shelter Cluster (GSC): This committee supports people affected by natural disasters and conflicts that strives for safe, dignified and appropriate shelters. The GSC is a platform with 35 regular partners, of which UN-Habitat is one of them. On global level GSC works on technical capacity and system-wide preparedness in order to respond to humanitarian emergencies, they support country-level shelter clusters. They collect, analyse and share best practices and lessons learned via their website. On country level (Nepal) Shelter Coordination Teams mobilize groups of agencies, non-government organizations, local and national governments, the International Red Cross and Red Crescent Movement to respond in a strategic and accountable manner. In the case of post-earthquake Nepal they also established a GSC Working Group, called the Recovery and Reconstruction Working Group (Cluster).

Recovery and Reconstruction Working Group (RRWG): The RRWG is a working group initiated by The Global Shelter Cluster, working task-oriented and time-bound with clear deliverables. In parallel there are also Technical Working Groups were also companies and engineers come up with technical solutions. The RRWG is led by the Strategic Advisory Group of which UN-Habitat (leading organization) and the DUDBC are part (Appendix 1.E., Shelter Cluster)

UN-Habitat: This United Nations programme works towards a better urban future, by promoting sustainable human settlements development and achieving shelter for all. Already before the earthquakes UN-Habitat was running 7 projects between 2008 and 2013 with a budget of $7.074.204 (). Post-earthquake they amongst other things cooperate with Arcadis and KU Leuven in order to design new plans for Bungamati, an urban historical settlement close to Kathmandu.

Prime Minister's National Relief Fund (PMNRF): The PM Relief Fund is a fund that accepts voluntary contributions. The resources in the fund are used for rescue, treatment, relief and rehabilitation of families who are victim of natural disasters (). For the long term process of reconstructing Nepal this stakeholder is not of big importance since they focus on the first needs after a natural disaster.

National Society for Earthquake Technology (NSET): The NSET is a non-governmental institute founded in 1998 with the vision to realize earthquake safe communities in Nepal by 2020. The institute constitutes professionals belonging to various technical and social aspects of earthquake disaster management. It wants to reduce the impact of future earthquakes, and raise awareness on disaster reduction, contribute to science and technology (N. Nepal).

Municipality vs. VDC: Nepal's 75 districts are divided into municipalities and VDC's, which both serve the same function. One of their key responsibilities in this context is to award construction permits and control the permitted executions. Municipalities are the governmental body in town areas and the VDC's in (smaller) villages. Eventually municipalities and VDC's are divided into so called wards, with their own committee (WC) (Democracy). The earthquake control on building codes has been sharpened since the 2015 earthquakes. The severity of control depends on whether your construction site is under the legislation of a municipality or a VDC. Municipality control is stricter and require constructions sites to have their permits, otherwise the structure will not get access to the water and power grid. VDC's deal with a lack of engineers and therefore cannot control new structures in a qualitative way (Appendix 1.E., NSET).

Special Envoy for Reconstruction Efforts: Shesh Ghale, president of the NRNA (Non-Resident Nepali Association), has been appointed as Nepal's special envoy to raise necessary funds for rehabilitation and reconstruction efforts (Republica, 2015). The government appointed him as the Special Envoy to collect funds, since the PDNA pointed out $6,6 billion is required to rebuild Nepal.

Kathmandu Valley Town Development Committee (KVTDC): The KVTDC is responsible for overall planning and regulation of urban development within the Kathmandu Valley (ICIMOD, 2007). They also formulate building byelaws

Table 3.4, on the next page, identifies the stakeholders on their interests and power. The table is based on interviews and background research with the named stakeholders. Some stakeholders also have interests in Nepal other than post-earthquake aspects. Power is based on whether stakeholders can affect the issues future (Bryson, 2004). The issue on which their interest and power is described, and later assessed in a Power-Interest grid, can be formulated as: *rebuilding Nepal on a large scale for the long term with the focus on safety, feasibility, resources, culture, sustainability and functionality.*

Stakeholder	***Interest***	***Power***
DUDBC	Organizing large scale projects to rebuild Nepal. However besides the earthquake situation they also have other interests on urban developments and constructions.	High power since they are a governmental department, however they are constrained to governmental budgeting which are mostly yet to be collected.
NPC	Advise the government on vision, planning and policies	Low power; the NPC is an advisory body.
GSC Nepal	Give (technical) support to parties involved in reconstruction	Low power since they do not have legislation in Nepal, they provide support
RRWG (and technical working groups)	Bring all involved parties together	Low power since they do not have legislation in Nepal, they provide support
UN-Habitat	Running its own projects with their own budget. They are also interested in collaborating with other organizations in order to work on a national scale (RRWG)	UN-Habitat has its own budget
PMNRF	Bring relief to those affected by the earthquake in the form of rescue, treatment, rehabilitation etc.	The PMNRF has its own budget and controlled from the PM's office
NSET	Assess damage, train masons and construction workers, create awareness on disaster reduction	Low power since the NSET is non-governmental and functions as a knowledge institute
Municipality	Legislation and control	High power due to their blocking power as a legislative body
VDC	Legislation and control	Their power is less than the Municipalities since their resources and level of control are less.
Special Envoy	Raise funds for the Nepalese government to spend on rehabilitation and reconstruction efforts	Low power since they are a 'networking' organization

Table 3.4. Stakeholder identification map (Shock Safe Nepal group 1).

The power-interest grid of figure 3.12. categorizes whether stakeholders are subjects, crowd, players or context setters. Due to the common interest of 'rebuilding Nepal' no important stakeholder has a low interest. The difference in interest amongst stakeholders is small since all parties are interested in reconstructing the country. The 'Subjects' are stakeholders with high interest but low power and therefore in general do not pose a threat to the process. Subjects are: the Special Envoy for Reconstruction efforts, NSET, and Global Shelter Cluster (Nepal). 'Context Setters' have high power but low interest, their rules and regulations may form restrictions. Context Setters are: VDC's and municipalities. 'Players' are stakeholders with high interest and power, they can be seen as key stakeholders. Players are: the Recovery and Reconstruction Working Group, UN-Habitat, and the DUDBC.

It can be concluded the DUDBC is one of the players in this issue, they have the power and the interest to work towards rebuilding Nepal on a large scale. It is advisable to include them when working on large scale construction plans. Even though the VDC and Municipalities have shared interests with other stakeholders they can implement blocking power due to their legislative and controlling nature, therefore need to be included in the decision making as soon as plans become tangible. In the Subjects category stakeholders who are interesting to cooperate with are included.

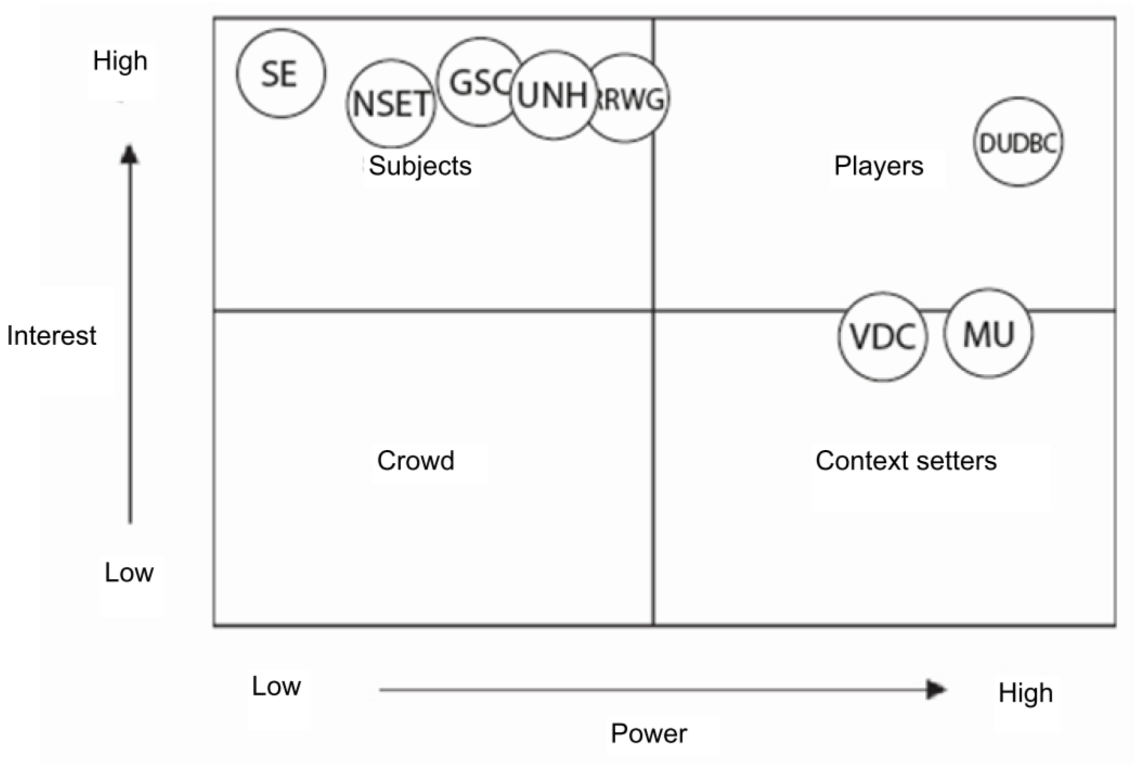


Figure 3.10. Power-Interest Grid (Shock Safe Nepal group 1).

3.11 Construction market analysis

The construction market includes materials as well as labour. The following chapter describes quality, availability and cost based on interviews, experiences in Nepal, and data of the CBS.

Quality

Quality of building materials are given by the building code standards (NBC 101: 1994), materials have to comply with Standard Certificates. Not all materials are in the Nepalese Building Codes, therefore Indian Building Codes are incorporated to complement. Materials that don't have a standard certificate need to comply with the requirements given by the BC or similar international standards. However quality of construction material might not be comparable to Western standards.

Availability

In order to reconstruct the +- 750,000 houses construction material is required. Main construction materials in Nepal are: cement, sand, aggregate, stone, mud, rebar, CGI sheets, burnt bricks, sun dried bricks and timber. Due to the high demand of the moment prices have gone up. Due to 'India's unofficial trade blockade' construction materials are hardly imported in Nepal, also transport is complicated due to the fuel shortage. This increases the material prices even more and makes it hard to give a clear overview of the construction market.

Table 3.2. shows the projected demand (according to the PDNA) versus the annual production of construction material. However the annual production is based on the pre-earthquake situation, and seems not taking into account collapsed factories, missing personnel, lack of transport etc.

Construction cost

The following table shows the increase of construction material and labour costs, measured by the Nepalese CBS. Year 2008 until 2014 were compared to 2007, resulting in the average annual index increase. The table shows labour costs increase more quickly than construction material does.

As can be seen there is a projected shortage of burnt bricks, which is also noticeable in its current cost. Fortunately Portland cement is projected to be able to handle the demand. However due to doubts on quality house owners often import it from India. To preserve forests in Nepal it is necessary to arrange a permit to cut trees, which also makes it harder to use wood in construction. Steel profiles are quite uncommon and are imported from China or India. Common and easy accessible materials are bamboo and stone.

The increase in construction material cost can be divided into the separate materials. Especially brick, concrete and wood increased large amounts. With respectively 10,9%, 8,7% and 5,3% of the total cost of construction materials this has a big influence on the total market. The cost for wood especially increased explosively.

Labour in Nepal accounts for an average of 29, 50% of total construction cost. The following figure shows the index growth of costs for different construction jobs. 'Normal labour' saw the biggest growth, engineers the smallest.

Due to the current unstable construction market, because of India's unofficial trade blockade and the post-earthquake situation, it is complicated to come up with hard data on material
prices.

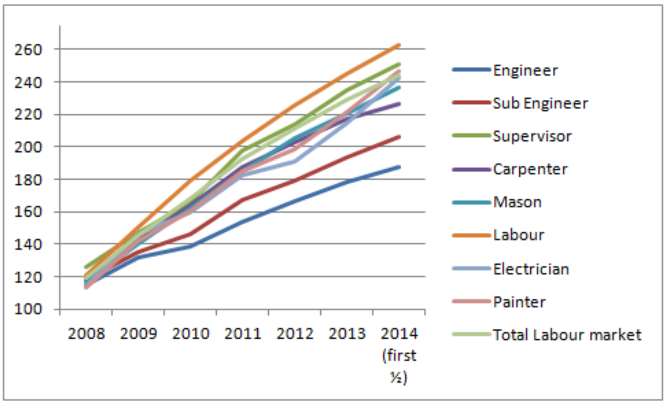
The location of construction site also has great influence on costs due availability and transport. Only an extensive survey, as performed quarterly by the Nepalese CBS, could give an indication on construction prices. However the CBS is constrained by the government for not sharing raw data and are therefore not able to provide us with actual prices.

Material	*Unit*	*Annual production (pre-earthquake)*	*Projected demand*
Portland cement	Million Ton	3,5	2,01
Deformed steel bars (10-25 mm)	Million Ton	0,75	0,14
CGI sheets (26G medium)	Million Ton	0,8	0,09
Burnt bricks	Million no.	430	1193
Timber	Million m3		0,55
Quarry stone/ rubble	Million m3		22,15
River sand	Million m3		2,61
Aggregates (10-20mm)	Million m3		0,83
Galvanized welded wire mesh (13 G 25x25 mm)	Million Ton		0,01

Table 3.2. Expected demand on construction material versus annual production (National Planning Committee, 2015).

Market	*% of total*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014 (first ½)*
Material	100	114,3	121,8	130,9	147,9	159	170,1	178,3
Labour	100	119,3	145,4	168,6	192,4	211,5	229,1	244,5
Total constr. sector	100	115,8	128,8	142	161,1	174,5	187,5	197,8

Table 3.3. Growth of total construction costs (National Planning Committee, 2015).



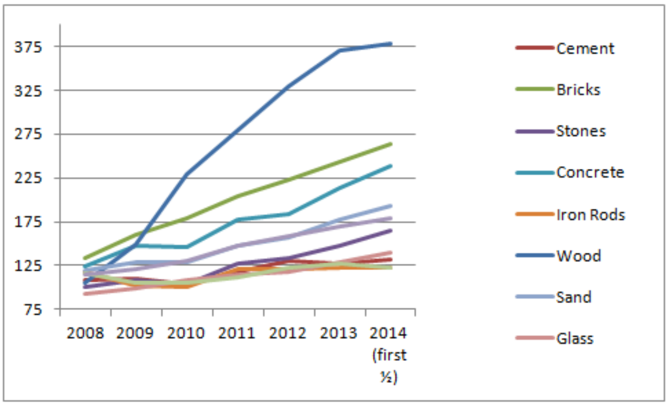


Figure 3.11. Growth of construction material costs (Based on (N. P. C. Nepal, 2015a)

3.12 Financial aspect of post-earthquake Nepal

After the April 25 earthquake a lot of countries gave aid to Nepal. There is no exact figure to the extent of this aid because the government but also numerous NGO's received foreign donations. Estimations indicate 4,4 billion USD (approximately 4 billion Euros) is pledged to Nepal (Appendix 1.E.) The PDNA estimates 6,7 billion USD is needed for the rehabilitation and construction of all the damaged sectors. (N. P. C. Nepal, 2015a) The first aid existed of emergency relief such as tents and food. The second phase exists of mid- and long-term recovery.

There is a difference in how aid is transferred to Nepal; countries could donate to the Nepali government into which they decide in the distribution of the funds or the countries donations could be distributed to various NGO's present in Nepal. The choice of the donating countries to distribute their funds between NGO's has a lot to do with trust issues present in Nepal's politics. Because of the unstable political situation countries want to keep control of their funds. For example the German government assist Nepal in its mid- and long-term recovery by a donation of 30 million euros. The support focuses on rebuilding: hospitals in the worst hit districts, infrastructure and energy sector support. All the support is coordinated by the German Embassy and implemented by the Deutsche Gesellenschaft fur International Zusammenarbeit (GIZ). With this setting the German government keeps control of its funds and knows exactly where the funds are being distributed (GIZ, 2015).

The government is currently working on a plan to support the inhabitants to rebuild their homes; in the financial speech of July 2015 the Ministry of Finance unveiled the details of the post-earthquake reconstruction works. The government has allocated NPR 74 billion (630 million Euro) for earthquake reconstruction works for the next fiscal year. Out of this budget NPR. 50 billion (430 million Euro) for housing, NPR. 3 billion (25 million Euro) for public buildings, NPR. 2 billion (17 million Euro) for archaeological structures, NPR. 7 billion (60 million Euro) for other physical infrastructures, NPR. 6 billion (51 million Euro) for production sector and NPR. 6 billion (51 million Euro) for the social sector will be spent. (M. o. F. Nepal, 2015) According to the Ministry out of the housing budget every earthquake-affected family will be provided financial assistance of up to NPR 200.000 (1700 Euro) and a soft loan of 2% to rebuild their damaged houses. Loans go up to 2,5 million NPR (21,000 Euro) for the Kathmandu Valley and 1,5 million NPR (12,500 Euro) for outside the Valley (M. o. F. Nepal, 2015).

3.13 Overall damage in Nepal

According to the Post Disaster Needs Assessment 755.549 houses were collapsed or damaged due to the earthquakes. Nearly half a million houses have collapsed, a quarter million was damaged, resulting in a total loss of €2, 4 billion.

Of all collapsed and damaged houses most affected houses were low-strength masonry, this building method also was the most common type as can be seen in table 3.6. Following chapters give an overview of typical damage to building methods and settlement types.

Table 3.5. Damage on private housing adapted from the National Planning Commission (2015).

Low-strength masonry	***Cement-based masonry***	***Reinforced concrete frame***	***Wood and bamboo based***
58%	21%	15%	6%

Table 3.6. Existing building typologies in the 31 affected districts (National Planning Commission, 2015).

	Number of houses	***Loss in NPR (million)***	***Loss in € (million) (rate of 6 Oct, 2015)***
Collapsed houses			
Low-strength masonry	474.025	199.091	1.702
Cement based masonry	18.214	19.671	168
RC frame	6.613	39.680	339
Total collapsed	498.852	258.442	2.209
Damaged houses			
Low-strength masonry	173.867	7.302	62
Cement based masonry	65.859	7.113	61
RC frame	16.971	10.182	87
Total damaged	256.697	24.597	210
Total	**755.549**	**283.039**	**2.419**

4. Settlement typology classification

An effort is made to classify the different settlements in Nepal into general classifications. Within this classification a majority of the settlements in the earthquake affected area can be classified. This generalization is used to create a quick overview of the settlement typologies of Nepal. The geographical locations are bound by the area into which earthquake damage has occurred. The area of classification is shown in figure 4.1.

Settlement typologies

To get a manageable overview of the housing situation the earthquake affected area of Nepal is divided in settlement zones. The zones ranked from A to E are shown figure 4.2. Each zone has specific building characteristics that will be explained in the following paragraphs, for each zone a SWOT is made to indicate the differences between the zones. The zones are based on existing overviews made by the DUDBC and UN-habitat. The main difference between the zones is their location that has consequences on the availability of materials, transport options, village size, income and building methods. Each zone has distinct needs and building topologies and can work as a blueprint for similar settlements throughout the earthquake affected area. Within the zones the most common typology of engineered or non-engineered buildings are indicated. Non-engineered buildings are buildings which are not formally designed but built using traditional techniques {Indian building code committee, 2013} More information about the building typologies can be found in the chapter: building methods.

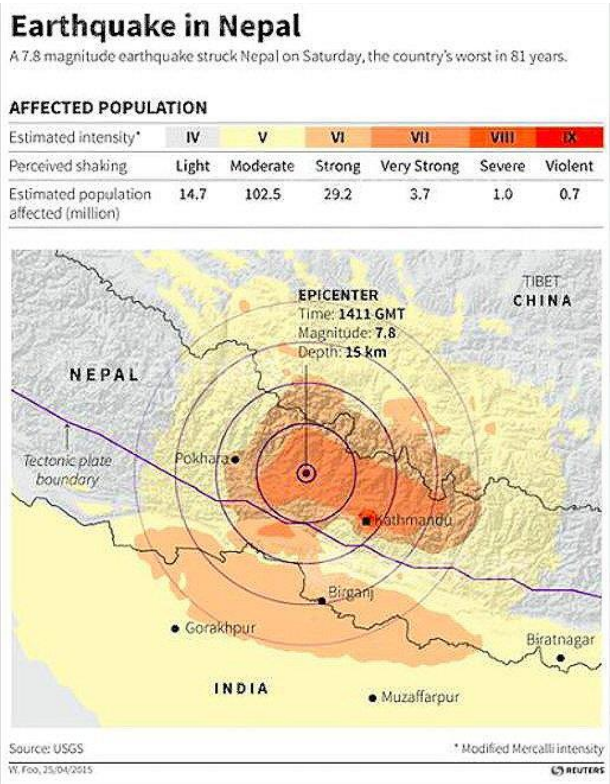


Figure 4.1. Area of earthquake destruction {Nepal National Information Technology Centre, U.S.G.S.}

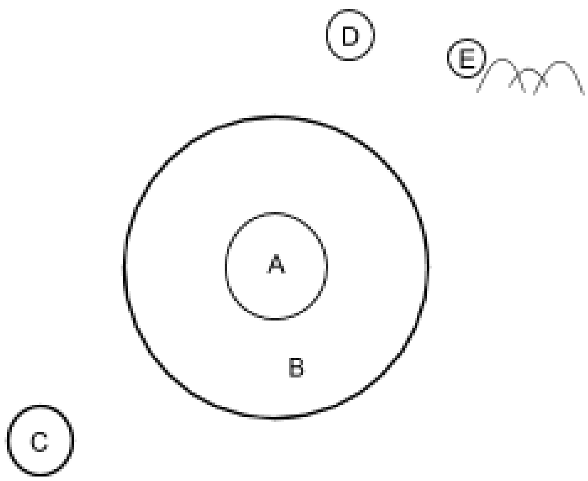


Figure 4.2. Settlement zones (Shock Safe Nepal group 1).

Figure 4.3. RCC building with discontinues load path (Shock Safe Nepal group 1).

Figure 4.4. Traditional brick masonry building (Shock Safe Nepal group 1)

Zone A: Urban core

In zone A the Kathmandu metropole centre is categorised, here constructing materials are available and there is no transportation issue. The price of land is high and is for that reason fully utilised, as a result concrete multi-storey structures have taken over the scenery. The major cities do have important historical heritage sites which make the area also attractive for tourism.

Most characteristic building methods:

- Reinforced Concrete Frames
- Low strength brick masonry
- Brick masonry

Characteristics:

- Mostly engineered buildings
- Historical and traditional build heritage sites

Damage assessment

Extensive damage reports can be found in Appendix 1.B.

RC-frame buildings

Many vulnerable factors are seen with respect to discontinuous load paths (cantilevers), lack of redundancy and bad quality of construction and detailing.

Brick masonry and traditional brick masonry buildings

Most of the severe damage caused in the urban core can be found in the old masonry structures. Many of these older buildings were built in the traditional Newari style (timber decorations). Newer brick masonry buildings are made with sober timber window frames and sometimes concrete slabs as flooring. Many vulnerable factors are seen with respect to lack of maintenance and lack of coherency between building elements.

Site visit report: Lalitpur, Kathmandu centre

At first sight the damage in Kathmandu seems limited but after a few days the destruction of the earthquake becomes more visible. The earthquake happened half a year ago and a lot of the debris has already been cleaned up but if one deviates from the beaten track the damages is still visible. Most concrete frame buildings are damaged and large cracks show they are not safe anymore. Eventhough the cracks could also indicate the building performed well during the eaerthquake, afterall the energy causing the cracks as absorbed, it now needs retrofitting. In the historical parts of Kathmandu the destruction of the earthquake is most visible, on the three durbar squares of the metropole complete historical buildings are missing, their historical artefacts are stored in the hallways of other historical buildings. Many old masonry brick buildings are propped by poles and still inhabited, with the risk of collapsing.

Key problems due to earthquakes

In Kathmandu many concrete and brick structures are heavily damaged but not collapsed. The damaged structures are only fixed aesthetically, by plastering and repainting the cracks, but their structural damage remains. Because many concrete structures did not collapse during the earthquake people belief they are safer for earthquakes than brick masonry. This reasoning is unfortunately based on a comparison between a 100 and 10 year old building. The key problem of the concrete structures is the lack in executional knowledge and are for that reason not necessarily safer for earthquakes, it depends on skilled craftsmen.

Research topics

- Retrofitting/repairing the damaged RC frame and brick masonry houses

Numerous buildings in this zone are damaged badly, however are 'repaired' for instance by adding a new layer of plaster. The internal damage of walls and structural elements however remains damaged and therefore adds risk in future earthquakes. What feasible methods can be used to retrofit these buildings? Is demolition and new development safer?

- Rebuilding historical heritage sites

Historical heritage sites (Durbar Squares, numerous temples, centre streets etc) are main touristic attractions of Nepal. Unrestorable damage could harm the tourist sector, which is of importance for the economy in the Kathmandu Valley. How should heritage be handled? Should traditional methods be used to safeguard the historical values or are modern techniques required?

- Control on/building according building codes

At the moment the 1994 building codes are being rewritten. As soon as they are published they need to be implemented and respected by all building parties. In the past building codes were often not respected, which added risk to the situation. What would be a successful organisational implementation to assure building codes are respected? Is there a difference between the top (site manager) and bottom (labourers) in knowledge on the building codes? Is project management sufficiently present on site?

- Demolition of severely damaged buildings

Several buildings in this zone are severely damaged beyond repair, however are surrounded by other structures. These buildings are now held up by temporary wooden and steel supports and pose a threat for its surroundings. There is a lack of equipment and funds to demolish all buildings. How can demolition be executed in a safe way without damaging surrounding buildings?

- Logistical challenge due to limited space

Zone A houses numerous small historical streets which makes it inaccessible for larger equipment and transport. The limited space also has effect on the flexibility of the construction site. What methods could be developed or already exist that can deal with this logistical challenge? Should new urban planning take this into consideration and propose wider urban space?

SWOT Zone A

Strength	Weakness
• Availability of resources (materials, labour and knowledge) • Capital city; nationwide priority • Most sites cleared of debris • Large motivation to rebuild • Resources to invest available	• Expensive land price • Buildings constructed close to each other • Limited availability of land for new construction • Limited capacity of Infrastructure
Opportunity:	**Threat**:
• Reconstruct monuments (temples) in order to restore tourism • Able to implement construction improvements • Able to implement logistical improvements • Possibility for improvement of urban planning • Efficient control on new building codes could improve the structural integrity	• Severely damaged buildings can harm surrounding buildings when demolishing • Severely damaged buildings will not be demolished at all • Construction of unsafe multi-storey buildings • No funds to repair damaged buildings, risk remains or bad repair • Not retrofitted buildings are still a risk during next earthquake

Figure 4.5. Uncontrolled construction of brick masonry (Shock Safe Nepal group 1).

Zone B: Urban village

Zone B lies outside the ring road of the major cities, the areas are in close connection with the major cities but are less attractive for commercial activities (see figure 4.6). For that reason the price of land is less than in the urban core. Because of the close connection to the major cities all material are available and there are no transportation issues. The urban villages started to grow as the major cities expanded, but lack the historical heritage which is found in the urban core.

Most characteristic building typologies:

- Reinforced concrete frames
- Brick masonry

Characteristics

- High amount of corrugated sheets/temporary shelters
- Engineered and non-engineered structures

Extensive damage reports can be found in Appendix 1.B.

The outskirts are characterized by an urban sprawl of non-engineered buildings. Most problems are seen due to informal construction, discontinuous load paths, unfavourable configurations and building on slopes

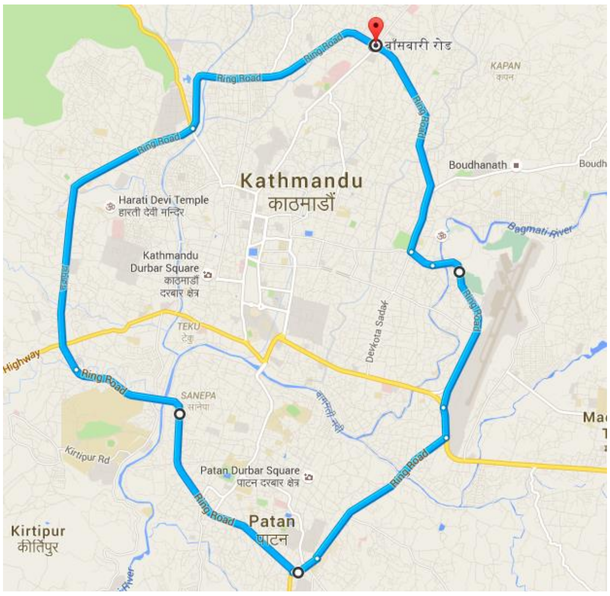


Figure 4.6. Ring road of the major cities (Google Maps, 2015).

Site visit report:

In urban villages people from the earthquake affected rural parts of Nepal gathered to find a safe shelter. Therefore a lot of tents and shelters made with corrugated sheets can be found. The people living in the shelters are either dependent on the government to get the resources to reconstruct their house in the rural area or too afraid to move back to their villages because of the loss of relatives or total destruction of their village. The original inhabitants of the urban villages mostly have less financial resources than inhabitants of the urban core, therefore their houses were of less quality and more damaged during the earthquakes.

Key problems due to earthquakes

Emergency shelters which are built for temporary use have a risk to become permanent, since people are waiting on the government to provide the resources to reconstruct. The houses which are been rebuild are built for emergency needs and not build according to the building code which make them unsafe in future earthquakes.

Research topics

- Designing feasible low-tech housing

Zone B is dealing with more financial challenges compared to Zone A. A threat for this zone is impoverishment of the build environment, either because of poor design/execution or because of temporary housing turning into permanent house. Which feasible building methods/materials can be implemented on large scale? What alternative is there for corrugated sheets, since it affects the cultural values?

- Unattractive nature of Zone B

Zone B is less attractive than its surroundings; the city centre and historical settlements. It lacks financial injections and the touristic activities offered in zone A and C. This combination causes the threat of slow development after the earthquakes, compared to other zones. How can this area change towards a more attractive zone? What catalyst could initiate this? Could aesthetically attractive housing initiate this?

- Uncontrolled construction

Even though control on permits and building codes is supposed to be sharpened, zone B still offers room for uncontrolled construction, meaning people build or extend their houses 'randomly' throughout the zone. These types of construction can cause additional risk during safety. How can these constructions be controlled?

- Upgrade urban planning

The whole city plan of zone B needs an upgrade; the area is mostly build informally and therefore not according city planning regulations. Roads are narrow and in bad condition causing problems when assess by emergency service. Besides that a working sewage system is lacking. This is mostly an urbanism challenge.

Figure 4.7. Uncontrolled RCC-frame buildings with unequal column length

SWOT Zone B

Strength:	**Weakness:**
• Short distance to resources (materials, labour and knowledge) • Large labour force available • Close to main infrastructural arteries	• Limited financial resources available • No focus point of relief organisations • No focus point of government • Not all sites cleared for reconstruction
Opportunity:	**Threat:**
• Able to implement construction/logistical improvements • Able to improve scenery / make the area more attractive	• Temporary housing becoming permanent housing over time • People from outside of the valley do not move back to their original houses

Figure 4.8.Trail of collapsed buildings (Shock Safe Nepal group 1).

Zone C: Urban historical settlements

Zone C are smaller settlements which are not directly connected to the urban core. The settlements were founded a long time ago but contrary to the urban core did not lose their historical character. The buildings are mainly constructed with traditional building methods and craftsmanship.

Most Characteristic building typologies:

- Low strength (brick) masonry (for example Newar)

Characteristics

- Non-engineered

Damage assessment:

Extensive damage reports can be found in Appendix 1.B.

These settlements are characterized by clusters of traditional brick masonry buildings (Newari style) and newer RC-frame buildings. Many traditional buildings have collapsed or are severely damaged. The main reason is bad maintenance of timber elements and inadequate connections between building elements. The relatively newer concrete buildings have performed better during this quake, also due to their smaller age. But also these buildings form a threat in future quakes due to discontinuous load paths, weak storeys and low quality of construction and detailing.

Site visit report: Bhaktapur, Sankhu, Bungamati

In the historical settlements the destruction rate was very high, the traditional building methods survived multiple earthquakes over the last 100 years but were unable to cope with the 2015 earthquakes. The settlements still show flashes of the beauty they once had but this might change soon: for example the owner of a damaged Newari house in Sankhu has impressive woodwork window frames but he wanted to sell them to build a new concrete frame house. In

Bhaktapur a combination between concrete frame housing and maintaining the historical aesthetics of the city has been made. The newly constructed buildings are completely made as a concrete frame, with only the front facade made from traditional materials.

Key problems due to earthquakes:

The settlements got their character and income from the traditional constructed buildings. The craftsmen making the constructions and woodwork sell their skills in a wide area and the traditional character attracts tourists to the settlements. With the destruction of a lot of the traditional build houses the chances are that the settlements lose their character and so craftsmen lose their skill set. Many people lost their home and want to reconstruct as soon as possible, the cost of a concrete frame building is less and takes less time to build than a traditional build house. The risks are that the settlements will be rebuild with concrete.

Research topics:

- Combining earthquake safe housing while maintaining the traditional character.

The cultural and historical values of buildings in this zone are of importance for its identity and touristic sector. In Bhaktapur for instance RC frame houses are now rebuild with traditional brick facades. Is this the most beneficial way to rebuild historic settlements?

- Maintenance of traditional housing

Traditional build houses require more maintenance, mainly because of the use of timber as structural (and non-structural) elements. Poor maintenance of timber cause the structure to perform less during earthquakes. Maintenance results in additional costs for the house owner, are there feasible maintenance methods which makes traditional houses still attractive to own?

- Use of historical artefacts in reconstruction

The earthquake destroyed many historical monuments, however many building materials are still intact. These materials are of historical value and should therefore be used during restauration/rebuilding of the monuments. The historical (Newari) woodcarving is an example.

Figure 4.9.: Brick masonry heritage with a newly added floor (Shock Safe Nepal group 1).

SWOT Zone C

Strength:

- There is high interest in reconstruction since these settlements are of high cultural/historical value and important for tourism
- Attention of foreign aid organisations
- High people's participation for the construction of religious structures
- Strong village identity

Weakness:

- Restrictions in reconstructing due to the historical values
- Damaged historical items lie out in the open
- Large part of the workforce moved to the major cities

Opportunity:

- Preservation of historical artefacts
- Utilizing the available traditional craftsman

Threat:

- loss of historical value due to reconstruction/ new construction
- Time and weather conditions will destroy historical items
- Building in a traditional way might be more expensive
- Traditional professions are vanishing (masons, timber etc.)

Figure 4.10. Soft storey collapse of RCC-frame building *(Shock Safe Nepal group 1).*

Figure 4.11. Buildings on a slope, discontinuous load path because of construction on the slope (Shock Safe Nepal group

Zone D: Rural village

Zone D consists of villages which are hard to reach from the urban core but are connected by a road. The villages form the entrance points to the remote areas. Rural villages are changing from traditional build rubble stone houses to concrete frame buildings. Most materials are available but the cost of transportation might be higher.

Most characteristic building typologies:

- Low strength (stone) masonry
- Reinforced concrete frame

Characteristics

- High amount of corrugated sheets

Damage assessment

Extensive damage reports can be found in Appendix 1.B.

In these settlements vulnerabilities are seen in construction quality and building configuration; soft/weak storeys, and discontinuous load paths.

Site visit report: Dhunche, Chisapani

The village of Dunche is one the main entrance points to the trekking region of Langtang, for that reason the village gets a lot of income from the lucrative tourism industry. This means that the village is rapidly growing and multi-story concrete frame buildings are replacing the traditional rubble stone houses. Since the rural villages are situated against the mountain regions there is a lack of level construction ground and with the village growing many of the buildings are built on or against a slope. After the earthquake a lot of destruction was seen in the concrete frame buildings, showing they are not necessarily safer.

Key problems due to earthquakes:

The rural location and the rapid growth makes that buildings are constructed with haste and not according to the building codes, since the area is situated more than half a day away from the heart of the country where most of the engineers are located, less design expertise is available. This is a problem since the buildings are evolving into more difficult multi-storey buildings constructed on a steepening slope. Also the availability of experienced construction workers is problematic since most of the houses are built by the house owner.

Research topics

- Safely construct on slopes

Especially in ribbon developments people have benefit of building their house directly connected to the road because of the commercial advantages. However buildings connected directly to the road have several characteristics which are disadvantageous during earthquakes. They are built on a slope, have unequal wall/column length, difficult accessible construction site.

- Design of multifunctional structures (housing / workspace / restaurant)

The buildings have multi purposes, the ground floor is often used as a workspace with the other layers used for housing. The design of a floor should match its function without compromising on the structural strength of the building.

- Choice of material, transport cost, dependant

Zone D offers more challenges regarding choice of construction material. Transport costs play a bigger role for this zone compared to A till C. Are there alternatives to transport, factories and plants for instance? Or can local materials cover the need for nonlocal materials?

- Implementation of different foundation types

Each construction site has its own foundation solution, research should be done in which foundations types are feasible in zone D and which ones have a preference when matched with a building method. Zone D is challenging due to the fact people build their houses on slopes and in general along roads.

- Re-use construction material

The areas in zone D are difficult to reach, especially by large trucks used for the transportation of new building materials. Research should be done in the use of used material for the construction for new houses, to come up with a more feasible and environmental friendly construction cycle.

SWOT Zone D

Strength: • Tight communities create high people's participation. • Many commercial functions along the road • Situated at popular and economic attractive traffic routes • Extra income from the touristic sector as mountain station	**Weakness:** • High (er) transport costs • Often part of a VDC instead of municipality resulting in lack of control on building codes • Few appropriate building sites due to mountainous character • Additional difficulties of working in a landslide area • Limited financial resources
Opportunity: • Ability to combine work and housing function into one structure • Increase the area’s potential	**Threat**: • Villages are rebuild using corrugated iron sheets; temporary housing turning into permanent housing • The policy on cutting trees makes it harder to use local timber for housing (community forest)

Figure 4.12.: Low strength stone masonry house made with mud mortar (Smart Shelter Foundation).

Zone E: Remote village

Zone E consists of small villages only reachable by foot, for that reason not all building materials are available or transportation can be very costly. The houses are mostly constructed with local available materials, such as rubble stone, wood and mud mortar. The villages located at higher altitude deal with large temperature fluctuations.

Most characteristically building typologies:

- Low strength stone masonry

Damage assessment:

Extensive damage reports can be found in Appendix 1.B.

Remote settlements are threatened by site hazards such as land- (mud) and rock-slides. Risks are higher during Monsoon season when the slopes which have little vegetation holding the ground together with its roots. The majority of buildings is made of rubble stone masonry. These buildings are highly vulnerable to earthquakes due to heavy material, irregular stones and lack of coherency between building elements.

Site visit report: Laurebina, Gosainkunda

The villages are heavily affected by the earthquake, with most of the buildings damaged or collapsed. Many of the villagers abandoned their house and moved to another location. Prior to the earthquake most of the villages where self-sustainable and had an agricultural function. The villages which are located at viewpoints have lodges where tourist spent the night during their trekking. These villages get a significant boost from the tourist industry.

Figure 4.13. Loadbearing wall of low strength stone masonry has collapsed (Shock Safe Nepal group 1).

Key problems due to earthquakes:

Not only the buildings collapsed but also the landscape changed during the earthquake, landslides blocked the main tracks between the villages and some landslides even covered complete villages. Since the villagers moved to another location some of the areas could stay the same for years to come. The remoteness of the villages also limits the possibility to exchange and access earthquake safe construction knowledge.

Research topics:

- Restore infrastructure

Earthquakes and landslides caused some remote villages to be isolated because of inaccessible routes. It turned out this accessibility caused the emergency relief to arrive late, but also causes trouble during reconstructing the villages. How can routes be constructed on a national scale? Are there ways to make the routes more durable?

- Distribution of knowledge on earthquake safe building

Nepal has a lot of knowledge on earthquake safe housing, however this knowledge is not distributed throughout the country. Distributing this knowledge would avoid poorly built houses. How can we share in knowledge with masons, labourers, and home owners on a national scale?

- Earthquake safe designs with local materials

In remote villages not all materials are available, some materials are nearly impossible to import, some are costly to transport to the village. What materials are feasible to transport to remote villages? How can local materials be used to design more safe buildings? Should certain materials be produced on site or locally to generate more availability?

- Choice of the correct building sites

Since the zone E areas are so remote not all materials are available or feasible to construct an earthquake safe house. A big part of the solution in building earthquake safe houses is the choice of the correct building site. The correct building site could reduce the risks for landslides and limit the damage.

SWOT Zone E

Strength: • High people's participation • Part of the construction material is locally available • Unique character of the buildings • Preserving the environment by re-use of materials	**Weakness**: • No road access • Lack of (new) knowledge/education • Part of a VDC instead of municipality resulting in lack of control on building codes • Villagers left the villages • Only the traditional building methods are locally available • Very limited resources (labour, materials, knowledge) • Limited suitable construction sites
Opportunity: • Use existing materials in an innovative way • Implement educational programs on earthquake engineering basics • Create extra income by accommodating tourists.	Threat: • People not returning to the villages, remain abandoned • Local building materials are not sufficient enough to withstand an earthquake

5. Principles of earthquake resistant building

Parts of this text have previously appeared in modified form in the thesis 'Earthquake engineering, balancing conflicting objectives'(Wijnbergen, 2015).

There are basically 3 main methods (Figure 5.1)
a) Resistant: making the building stiff or strong enough. This conventional method costs a lot of material.
b) Vibration control: creating a more flexible building, but dissipating the seismic energy.
c) Base isolation: reducing acceleration by changing the natural building period.
Resistant methods are based on strength and stiffness. The approach is based on an appropriate structural configuration, mass distribution, choice of material, careful detailing of structural members and connections(MCeer). Architectural decisions are bound and framed by structural objectives as avoiding torsion, discontinuities, set-backs and promoting symmetry, continuity and regularity (Beltran, 2014).

Vibration control and base isolation can comprise high-tech and expensive measures which are not feasible in countries such as Nepal. Measures of damping and base isolation are seen in the form of material use; such as the damping by yielding of mud mortar (fig. 5.2), or temples which are set on a stone base (fig. 5.3).

The main earthquake principles are classified into several categories and mentioned in the following paragraphs.

Figure 5.2. Masonry and stone mortar (Shock Safe Nepal group 1).

Figure 5.3. Traditional temple on a stone base (Shock Safe Nepal group 1).

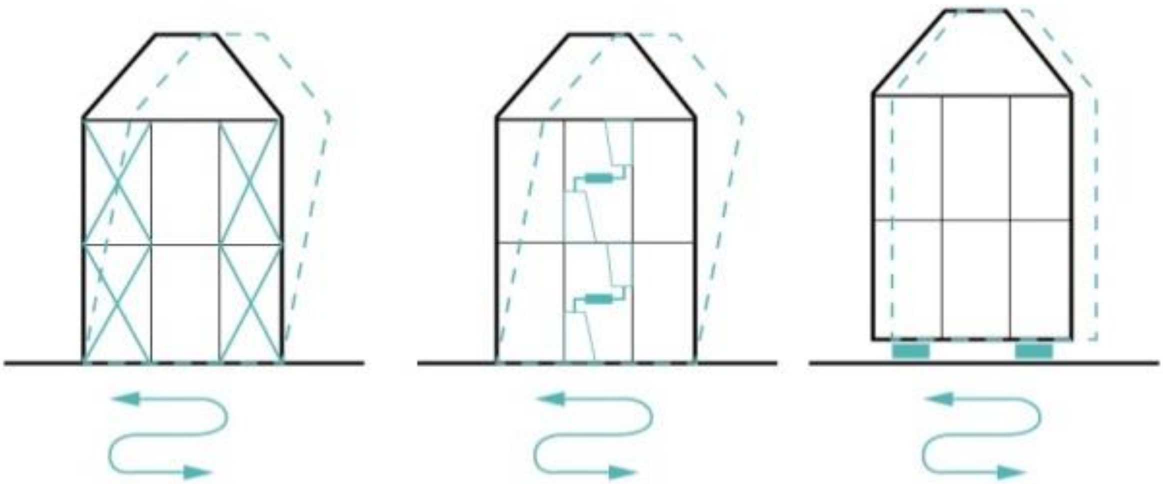


Figure 5.1. Main earthquake resistant construction methods: resistant, vibration control, base isolation (adapted from Japan property central).

5.1 Global strength, stiffness, stability and ductility

Choice of material and detailing

It is favourable to use materials with a high ductility, such as well-detailed steel, timber, reinforced concrete, reinforced masonry and design details with enough ductility and deformation capacity. This characteristic allows the structure to deform and dissipate some of the earthquake energy without instantly breaking (without warning).

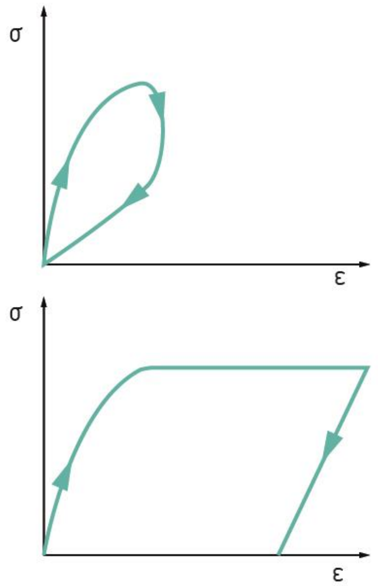


Figure 5.4. Top: Stress strain graph elastic behaviour, Bottom: stress strain graph of plastic behaviour (adapted from TNO, 2014).

Flexible materials

Flexible structures, which allow some movement, have a good earthquake performance. This can be achieved with flexible materials such as timber, or motion space in the detailing of connections.

Limited mass

Seismic forces are directly proportional to building mass, it is therefore beneficial to build as light as possible. Timber, bamboo and steel frame structures generate less seismic loads due to low mass.

Figure 5.5. Building with light materials (Arup, 2014).

5.2 Building configuration and mass distribution

The building configuration and distribution of mass influence the flow of forces.

Distribution of seismic-resisting elements

By placing the resisting elements for seismic lateral loads, such as braces and shear walls, at the perimeter of the building, the greatest resistance is achieved since the lever arm will be the largest.

Regularity in plan

Regularity and symmetry in plan is important for the load transfer. The resultant of the forces is located in the centre of mass, whereas the centre of rigidity withstands the forces. A difference in location of these centres results in torsion, as can be seen in figure 5.4. The plan should be symmetric, including aspects as cut-outs of the floors. When designing the plan, one should avoid L, T, U, V, Z-shapes since these configurations introduce high shear stress and stress concentrations in the re-entrant corners. The plan setback should be at least 15% to be considered re-entrant. Also the length of the walls should preferably be equal in both directions; in any case not more than 3 times the width.

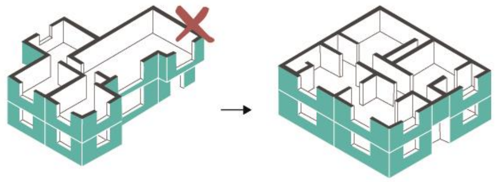


Figure 5.6. Regular plans are favourable above irregular plans (Adapted from Arup, 2014).

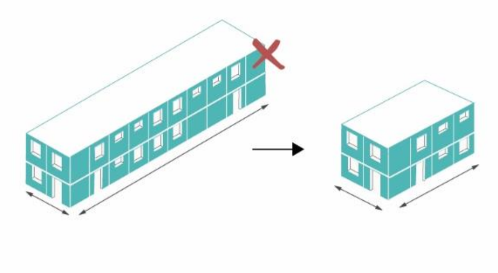


Figure 5.7. Dimensions max L<3B (Adapted from Arup, 2014).

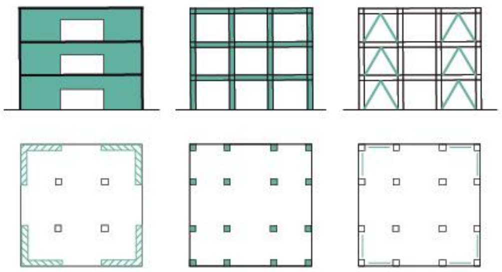


Figure 5.8. Resisting elements in the perimeter to create a larger lever arm (Adapted from Arup, 2014).

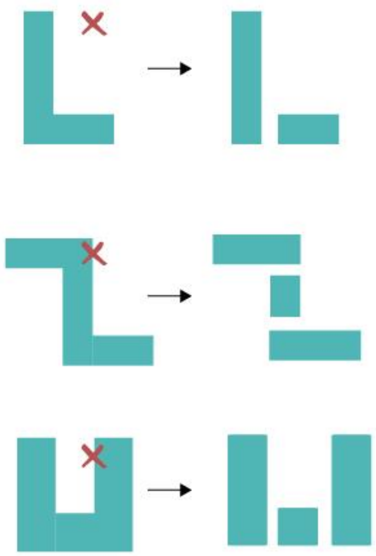


Figure 5.9 Regular plans are favourable above regular plans. Dilatations can be provided to avoid irregularity in plan lay-out (Shock Safe Nepal group 1).

Regularity in elevation

The elevation should also be designed regular and continuous with respect to load transfer, since sudden changes of stiffness can induce a concentration of forces. When changing stiffness in elevation, it is wise to provide a dilatation or split to the building. Flexible stories, open ground stories or ground floors with too many windows in combination with stiffer upper floors should be avoided and are problematic due to the difference in deformation. A disproportionate drift which is concentrated on a specific story can be the cause of collapse(Khan, 2013).

Distribution of live loads

Heavy loads (such as water tanks) should be placed lower in the building, to minimize the inertia forces. They should also be placed close to the centre of rigidity in order to avoid torsion.

Figure 5.10. Large live loads on roof due to water tanks (Shock Safe Nepal group 1)

Figure 5.11. Irregular shapes (Adapted from Arup, 2014).

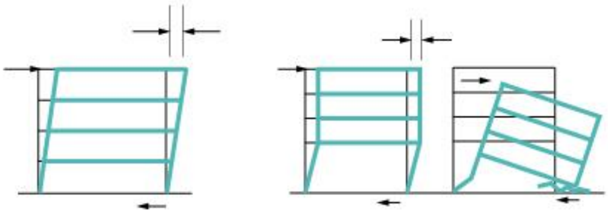


Figure 5.12. failure mechanism: Soft story effect (Adapted from Arup, 2014).

5.3 Load path

Interconnection of members

The connections between the walls and the diaphragms must be adequate. In this way, the building can withstand forces in a box-like manner.

Seismic bands for masonry

Masonry performs well under compressive loads, however it has low tensile strength if it is not reinforced. Vertical and horizontal reinforcement members are therefore essential for a good performance in earthquakes. Reinforcement should be provided by means of strong and ductile materials. Horizontal and vertical reinforcement should be adequately tied together.

Horizontal reinforcement

Horizontal bands are key elements to ensure integral action of masonry walls (Devdas Menon, 2008); to tie the wall leaves together. to ous and have a good connection with the wall (Garcia). The bands will reduce the tendency of out-of-plane collapse. Usually, the bands are provided at floor, lintel and roof level of a building. Combining lintel and roof band can save costs. Horizontal reinforcement helps to transmit the out-of-plane forces in transverse walls to the supporting shear walls, as well as to restrain the shear stresses between adjoining walls and to minimize vertical crack propagation.

Vertical reinforcement

Vertical reinforcement is necessary to connect the wall and foundation to the horizontal band. It helps in withstanding out-of-plane bending and in-plane shear.

Redundancy

By providing structures with a second load path, its redundancy will increase and it will not collapse entirely if individual members fail.

5.4 Building components

Stiff diaphragms

Stiff diaphragms distribute forces related to the stiffness of each wall, whereas flexible diaphragms distribute forces on the basis of mass. This means that the walls perpendicular to the loading will experience significant loads in the weak-out-of-plane direction, possibly causing local failure. By creating stiff diaphragms, the forces can be distributed to walls that are parallel to the forces, and therefore resistant to those in-plane forces, which is more favourable.

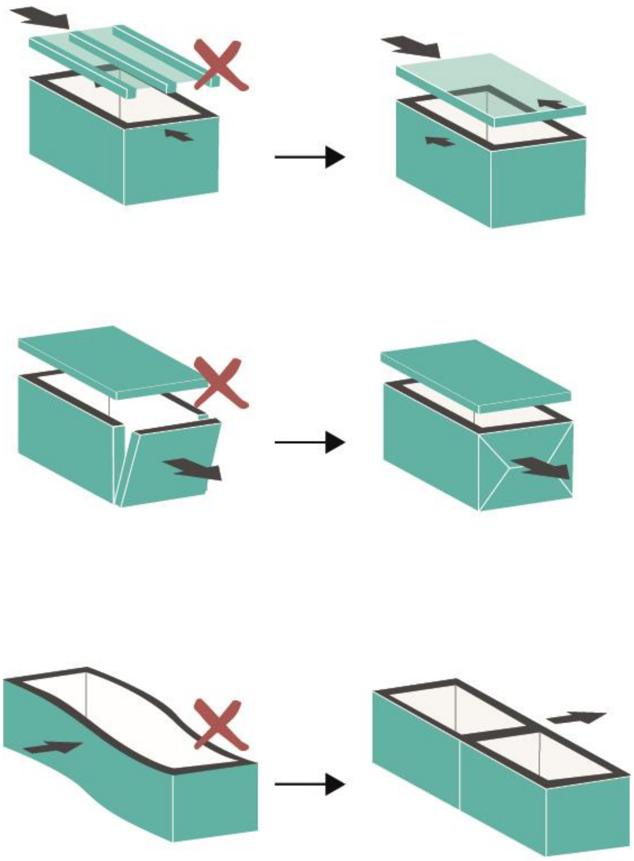


Figure 5.13. Stiff diaphragms provide a better load transfer (Adapted from Arup, 2014).

Walls

In the design one should avoid long unsupported walls. Seismic performance of walls can be increased by adding transversal walls or peers that act as an out-of-plane support for the wall, preventing inward or outward overturning {Blondet & Villa Garcia).

Furthermore a wall should not have too many openings; this will decrease its shear strength. In case of openings, take care of a direct transfer of forces between the cut-outs.

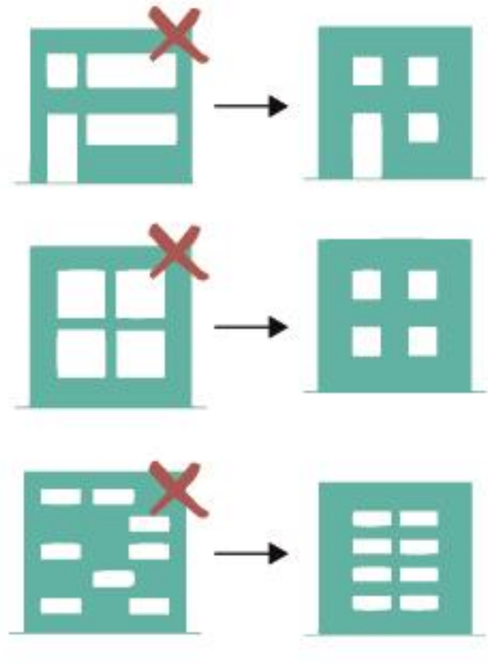


Figure 5.14. Limit the wall openings in diaphragms (Adapted from Arup, 2014).

A. Non-structural elements

Carefully design possible falling hazards which are non-structural elements such as: chimneys, parapets, outer leaf of cavity walls, ornaments, balconies and awnings. The detailing connection and fixation of these elements should be done with great care.

B. Reduce demand

Instead of strengthening the building, one can also try to reduce the loading demand. Buildings have an inherent ability to dissipate energy, this is called damping. However, damping by the building itself results in a degree of damage, since it is based on friction between elements.

Enhance damping capacity

By equipping the building with additional devices which have a high damping capacity, the damage can be limited.

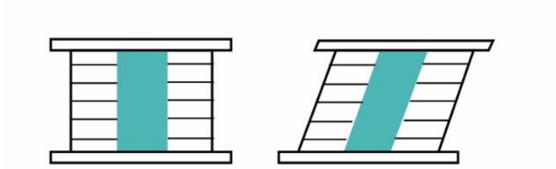


Figure 5.15. Damping device (Adapted from MCeer).

Isolate from ground

By setting the building on base isolators, the building will move, but it can retain its original shape (NAMplatform, 2014) without experiencing too much deformation. The natural period of the building will be longer, which reduces the acceleration of the structure.

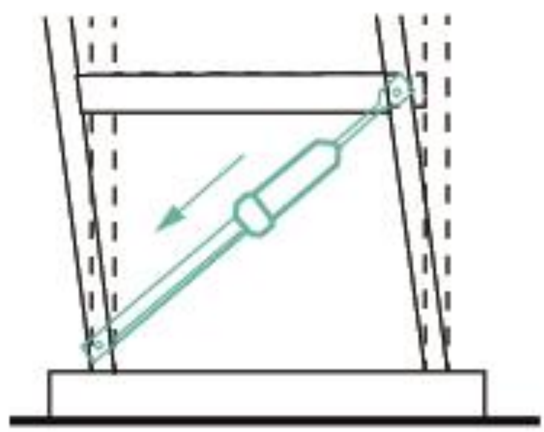


Figure 5.16. Lead-rubber bearing of base isolation (Adapted from MCeer).

6. Building methods

A preliminary selection of proposed buildings methods is made on the basis of interviews with local non-governmental and market parties, feedback from the Department of Urban Development and Building Constructions (DUDBC) in Nepal and input from World Housing Encyclopaedia based on the appropriateness for housing, the suitableness for low-rise buildings and the potential seismic resistance. This resulted in a list of building methods considered interesting for rebuilding Nepal. These building methods can roughly be categorized in three groups:

- Commonly used building methods in Nepal
- Reference building methods
- New building methods

In this section a summary of the findings is shown, in Appendix 1.A. building methods each building method is elaborated on: technical, recourses, feasibility, social/cultural, functional and sustainable aspects. This information should provide more inside in choosing the right building method when constructing in Nepal.

6.1. Commonly used building methods in earthquake affected area Nepal

The commonly used building methods in earthquake-affected Nepal can be either indigenous or foreign. These are the building styles that are known by the people and may be historically embedded in the Nepalese culture or are already being used for a very long time.

A. Low strength (stone) masonry

This building style is mostly found on foothills, hills and mountains in the rural and remote areas of Nepal {Parajuli, Bothara, & Upadhyay, 2015}. The buildings typically consist of river stone foundations, load bearing stonewalls, timber window frames, and varying roof/flooring systems. The walls are composed of two layers of mountain stone and the space between is frequently filled with mud, small stones and pieces of rubble (Brzev).

Figure 6.1. Stacked stonewall (Shock Safe Nepal group 1).

Figure 6.2. Low strength (stone) wall (Shock Safe Nepal group 1).

B. Low strength (brick) masonry

This building style is very common in old villages and towns of the Kathmandu valley. The buildings typically consist of river stone foundations, a combination of burned brick on the outer wall and sun dried brick masonry on the inner wall, the brick masonry is often held together with mud mortar. The he space between is frequently filled with mud, small stones and pieces of rubble stone. The average low strength brick masonry house has a basic rectangular design. Within this category the traditional Newari building style can be classified.

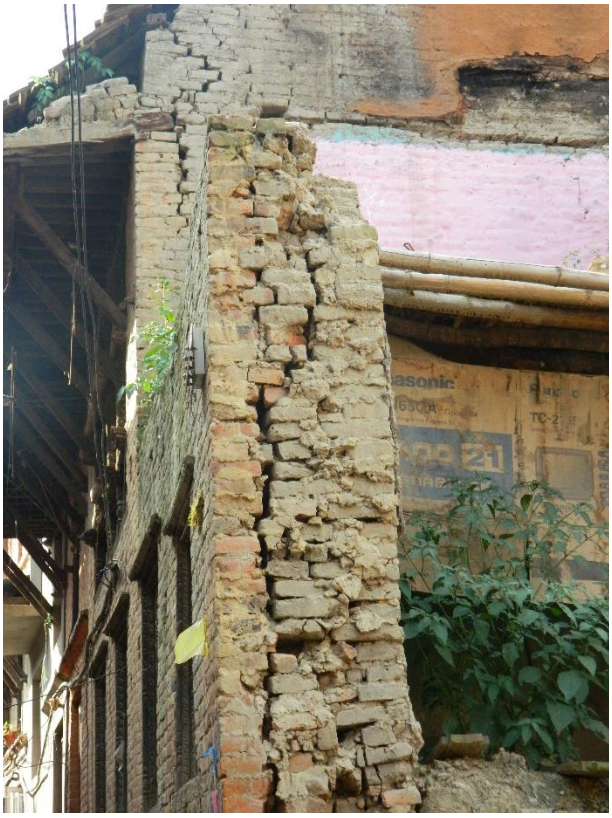


Figure 6.3. Low strength brick masonry, inner and outer wall (Shock Safe Nepal group 1).

Figure 6.4. Low strength brick masonry house (Shock Safe Nepal group 1).

C. Stone masonry in cement mortar

This building style is similar to stone masonry and mostly found in the more mountainous parts of Nepal. The houses consist of stacked mountain stones held together by cement instead of mud mortar.

Figure 6.5. Stone masonry with cement (Shock Safe Nepal group 1).

Figure 6.6. Stone masonry cement house (smartshelterfoundation, nd.)

D. Brick masonry in cement mortar

This building style is similar to brick masonry and mostly found the villages and towns of the Kathmandu Valley. The brick masonry is held together with cement instead of mud mortar to construct load-bearing walls. The walls usually exist out of multiple layers of brick

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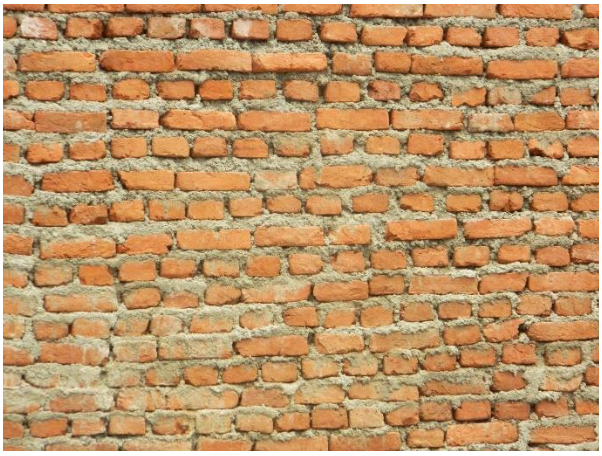


Figure 6.7. Brick masonry wall (Shock Safe Nepal group 1).

Figure 6.8. Brick masonry house in construction (Shock Safe Nepal group 1).

E. Hollow concrete block masonry

Hollow concrete blocks are used around the Kathmandu Valley and are popular in certain areas {Habitat Nepal}. The blocks are designed to have hollow compartments inside in order to reduce cost, the addition of these air pockets also makes the blocks fire resistant provides insulation. (Hornbostel, 1991)

The blocks are held together by cement mortar and allow for incorporation of rebar and cement in the air pockets for additional strength.

Figure 6.9. Hollow concrete blocks (Shock Safe Nepal group 1).

Figure 6.10. Hollow concrete blocks house (Shock Safe Nepal group 1).

F. Reinforced Cement Concrete frames (RCC)

This building type can be found widespread in urban and semi-urban areas of Nepal, and is one of the most emerging building methods (Yukta Bilas Marhatta, 2007 & Chapagain). An important distinction can be made between engineered and non-engineered (informally constructed) concrete frames. The main structural system is a moment-resisting reinforced cement concrete skeletal frame of cast-in-place concrete beams and columns with masonry infill walls. Infill is mostly solid clay bricks; infill with stone masonry is also seen in informal structures.

Figure 6.11. Reinforced cement concrete frame with brick infill house (Shock Safe Nepal group 1).

Figure 6.12. Reinforced cement concrete frame with brick infill house build on a slope (Shock Safe Nepal group 1).

G. Timber constructions

Timber constructions are often used in Nepal. They are often constructed in stud wall frame or wood frame construction, with either concrete or stone foundations. Walls are built out of vertical timber elements and are stiffened by plywood or gypsum board sheathing. The roofs are often executed out of timber joists or prefab timber trusses (Arnold).

Figure 6.13.: Timber framed house, infill of mountain stone (Shock Safe Nepal group 1).

Figure 6.14. Timber framed house, with a mountain stone foundation (Shock Safe Nepal group 1).

6.2 Reference building methods

The reference building methods are inspired by methods used in other earthquake prone countries with comparable geographical, income, and seismic characteristics and knowledge as Nepal. Some of the countries taken into account are Pakistan, Haiti, North India, Peru, Indonesia, but also some more advanced countries such as Japan and Chili. These reference-building methods often make use of cheap and innovative methods that are used in the different earthquake-prone areas around the world.

A. Adobe

This building method is common for low-income rural populations. The Adobe building method uses building materials such as earth, un-stabilized mud-like blocks or sun-dried bricks. This building method is one of the earliest building methods in the world, dating back to 8000B.C. (Houben). The typical building consists of a strip footing foundation, adobe material walls and floors spanned with wood joists. The roof is usually clad with clay tiles or corrugated sheet metal. (Garcia)

Figure 6.15. Construction of house made with adobe bricks (Municpio, nd.)

Figure 6.16.: Adobe house in Nepal that the quake (Shock Safe Nepal group 1).

B. Dhajji Dewari

Traditional building method in the western Himalayas, mostly found in Pakistan and India. Similar building methods can be found in parts of Europe and Central America (K. Hiçyılmaz, 2011). It is largely adopted as a rebuilding method after the 2005 Kashmir earthquake. The building method exists of an extensively braced timber frame filled with either stone or brick masonry held together with mud mortar. The method is generally laid on shallow foundations stone masonry (K. B. Hiçyılmaz, Jitendra ; Stephenson , Maggie, 2012). Flooring is done with timber beams, which span wall-to-wall, timber floorboards on top of the beams are overlain with a layer of clay/ mud. Roofs are either flat, timber logs with a mud layer pitched timber constructions with metal roof sheeting.

Figure 6.17.: Timber frame filled with mountain stone (worldhousing, nd).

Figure 6.18: Timber framed house filled with mountain stones (worldhousing, nd)

C. Rammed earth

This ancient technique is mostly used for residential purposes in many different countries. Also in Nepal it is used in many places ranging from the Terai (plains) to the Himalayas. Rammed earth is the in-situ ramming of moist soil into a placed mold (Sassu & Ngoma, 2015) to make foundations, floors and walls. Rammed earth is gaining renewed interest, due to its usage of sustainable and locally available building material. The roofs are mostly made of timber or bamboo structure (pitched) and clad with corrugated iron sheets.

Figure 6.18. Construction work of a rammed earth wall (Wentworth designs, 2009).

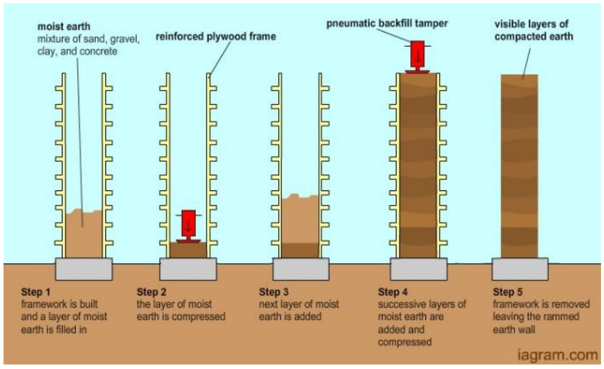


Figure 6.19. Section of a rammed earth wall.

D. Steel

Structural steel was predominately used for industrial and agricultural structures and found its up rise in the Second World War. () After the war the use of steel as a construction material for buildings, bridges and other structures was widely accepted and accessible due to its cost- efficiency. Nowadays steel is not only used for complex structures but also for regular housing projects in seismically active areas, such as Japan where the use of steel in building housing is subsidized.

Figure 6.20.: Steel framed house with brick infill house in Nepal (Shock Safe Nepal group 1).

Figure 6.21. Steel frame in Nepal (Shock Safe Nepal group 1).

E. Concrete in-situ shear wall

Buildings made with cast-in-situ reinforced concrete walls have been practiced since 1960. This type can be widely found in urban regions of seismic hazard areas such as Canada, Chile, Romania, Turkey, Columbia and the republics of the former Soviet Union (Moroni). Shear walls are usually placed along both length and width of buildings; they carry earthquake loads downwards to the foundation. Shear walls can be executed in several ways such as, all shear wall, tunnel or limited shear wall.

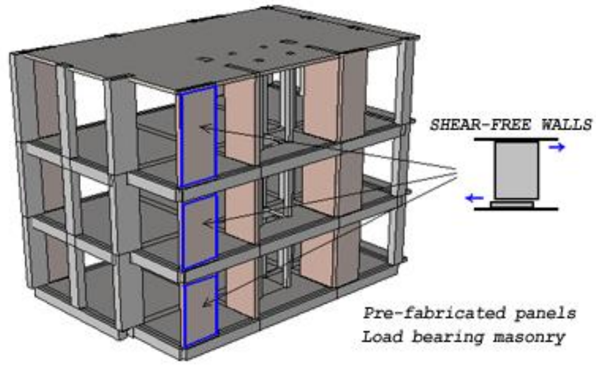


Figure 6.22. Placement of concrete shear walls in a structure (mahve, nd).

Figure 6.23. Construction of a shearwall (ENR, 2011).

F. Confined Masonry

This building type is found in urban and rural areas highly seismic areas, for example Chile. This type is practiced in most countries since the last 30-35 years, the building method gets its strength from tie-columns which are cast-in-place after the masonry wall construction has been completed. Tie-columns and tie beams work as ties that provide reinforcement to the structure. Reinforcement steel is needed to provide this tie function between the columns and beams. {Rodriquez}.

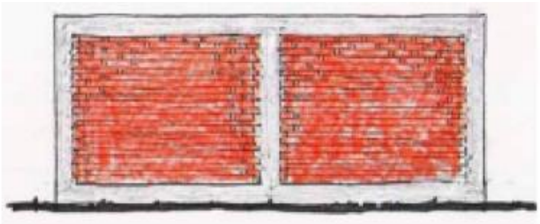


Figure 6.24. Confined masonry principle, load bearing infill walls (SCG, nd).

Figure 6.25. Construction sequence of confined masonry walls.

6.3 New building methods

The new building methods are not in all cases necessarily new, some of these methods use existing materials and techniques and incorporate them into a building in a different manner while others use an entirely new technique. Often these methods focus on the speed of construction, the affordable ness and use of lightweight materials that perform well when loaded laterally.

A. Bamboo

Bamboo is found in several forms in the construction practice in Nepal {Pokhrel}. It can be used as building material in combination with other materials. Floor or roof systems, or as an reinforcement for methods such as adobe or stone. Bamboo can be used practically for the majority of the housing components (walls, floors, roof, doors, windows, and stairs) but in practise is most common in the Terai region as building method and only as scaffolding in other parts of Nepal.

Figure 6.26.: Bamboo with corrugated sheet shelter (Shock Safe Nepal group 1).

Figure 6.27. Bamboo house designed for long-term housing (Kagay, n.d.).

B. Earthbags

The use of piled sandbags for the creation of walls is a technique that has been used for decades in flood protection and by the military in creating strong barriers. However the application of using sturdy bags filled with local materials for use in the construction sector is fairly new. () In building with earthbags different kind of methods are developed such as regular earthbags, super earthbags, hyper earthbags and sandsbags. Earthbags have been used in many countries to develop cheap and easy to construct houses. They can incorporate barbed wire and/or rebar for the strengthening of weak spots.

Figure 6.28. Construction of a house build with earthbags (Goodearthnepal, 2014).

Figure 6.29. Earthbag walls with a timber roof (natural building, 2010).

C. Interlocking Bricks

Interlocking bricks are bricks that form a connection with each other without necessarily the addition of mortar. The blocks are shaped with projecting parts, which fit exactly into depressions in the blocks placed above, such that they are automatically aligned horizontally and vertically which makes bricklaying possible without special masonry skills. The row interlocking of bricks that lie directly on the foundation is done with cement and must be completely straight. On top of that bricks can be laid down. In the end the holes can be filled up with cement and steel barns for reinforcement. Interlocking bricks can be made locally and consist of a mixture of cement and soil.

Figure 6.30. Machine used for producing interlocking bricks (Myib, 2015).

Figure 6.31. Construction of a house with interlocking bricks (Shock Safe Nepal group 1).

D. Light weight steel profile building systems (Veerhuis, Hulas, Finish Profiles)

This method is currently not widely used in Nepal but has been used in many disasters struck countries for rapid rebuilding. The building method makes use of steel plate rolls which can be bended into profiles on location, the profiles are easily connected by bolts and nuts, and the walls can be filled in with any type of material from local to Styrofoam.

Figure 6.32.: Lightweight steel house seen in Nepal (Shock Safe Nepal group 1).

Figure 6.33. Construction of lightweight steel framed house (veerhuis, 2012).

E. Prefab-framed in-situ concrete (Sismo)

Prefab-sandwich concrete panels are currently not used in Nepal but are used in countries with similar conditions. The frame exists of a simple construction made of hollow steel wire/ Styrofoam panels which should be filled with concrete, the method allows for the use of rebar and other strengthening's. To be able to construct these houses in Nepal a new factory and office need to be realized that works by importing styrene fluid for the creation of foam panels. The steel wire is the same as used in car tires and therefore a material that should be locally present. For harder to reach areas a mobile production system can be attached to a truck. The interior and exterior walls can be finished in any way, giving the opportunity to safeguard the Nepali architecture and culture.

Figure 6.34. Prefab-frames used for construction (SISMO, 2009).

Figure 6.35. Construction of a house with Rapidwall panels. (greencross, nd).

F. Single Panel Walling System (RapidWall)

Rapid Building Systems make use of Gypsum plaster products that are present in debris in the building and construction industry. The panel serves both as the internal and external wall and eliminates the need for bricks, blocks, timber wall frames. The panels are load bearing and can be used in single, double, or multi storey construction. RapidWall is mainly used in India and China, the two countries in which between Nepal is landlocked. Also both surrounding countries have Rapidwall factories (2009, RapidWall, presentation UN-Habitat).

7. Set of higher level requirements

In the previous chapters the problem space has been explored by defining the main problems in Nepal. Information is useful when considering rebuilding of affected Nepal has been categorised and documented. This information needs to be translated to a form in which it can be used for the definition of solutions fitting the problem. This chapter will elaborate on this process.

General idea

The bulk of generated information contributes to the definition of solutions that are suited for the earthquake safe rebuilding of Nepal. However this bulk of information can become disordered and inconvenient to use possibly resulting in the loss of information when designing. To enable the systematic and structural mapping of the criteria for housing, the theory of Wasson (2005) is used to define a set of higher level requirements. The aspects that are fixed for Nepal are described while the aspects that vary per specific settlement classification are left open to ensure the applicability of the requirements for all settlements typologies.

These requirements are initially abstract and describe the performance that is expected from a solution. While more information becomes available or is defined more clearly the set of requirements are updated, this happens in as a repetitive process.

Defining the aspects

To define clear requirements, the goal of a project needs to be clear. Having a clear goal allows for the creation of fitting requirements. This main goal is based on vision of the Shock Safe Nepal project and the gathered information being, the provision of a safe housing solution which is available, suitable and affordable for long term earthquake resistant construction in Nepal and which can be integrated in the local building and housing tradition.

To define the aspects to fit the main goal and problems a group workshop was organised. The input for this workshop was the information gathered in the first weeks of doing literature reviews, interviews and meetings and observations. This information was used to determine the important factors required to solve the problem. These factors were defined and combined into six aspects to keep it manageable. The following six aspects are defined: Technical, Resources, Feasibility, Social-Cultural, Functionality and Sustainability which together bound the 'solution space'.

1. Technical

The Technical aspect refers to the technical requirements that correspond to normal usage and seismic activity. It contains topics such as the seismic performance, the ability to improve seismic performance, the intended lifespan of a building, its climate performances and the amount and complexity of maintenance required.

2. Resources

Resources aspect refers to the construction materials, physical labour and, the knowledge and time needed for the construction of a house. It contains topics such as the availability of materials, the familiarity regarding a method and the compliance to the building code.

3. Feasibility

Feasibility refers to the monetary aspects with respect to the large scale rebuilding of Nepal and the impact on the local and national economy. Regarding the financial component it refers to affordability, the need for loans or external funding and government subsidisation.

4. Social Cultural

Social-cultural refers to the requirements that are related to the identity of a village or community, the way buildings are used in non-private manners and the effect of religion on the requirements of a building.

5. Functional

Functional refers to the functional requirements of a building with a certain use. It contains topics such as the ability for expansion, the functions for which a single building is used and how a homeowner lives in his/her house.

6. Sustainability

Sustainability refers to the possibilities regarding the reuse and recycling of materials, the production process and the ability for self-sustaining elements.

Sub-aspects

Each of the six main aspects is defined by smaller aspects related to the main aspect. And each smaller aspect is again built up from even smaller parts. These smaller parts are the sub-aspects of an aspect. The aspects and sub-aspects within a main aspect form the first cycle of narrowing down to the requirements. Table 7.1 displays some of the aspects and sub-aspects that fall within the main aspect 'Technical'.

Higher level requirements

Based on these multi-layered aspects, the set of requirements can be formulated with the use of all gathered information. New information can be coupled to existing requirements or new requirements can be formulated. Table 7.1 gives the requirements belonging to the aspects.

The full list of aspects and requirements can be found in Appendix 1.C Solution Space.

Results

With the use of the structure of the aforementioned six aspects and the information gathered in the report, a list of requirements to which each building method has to fit when constructing in Nepal is determined. These requirements are combined in a general requirements specification usable for the construction of houses in Nepal. When constructing in a specific part of Nepal the requirements specification needs to be extended to fit the requirements in that location. Thus forming a framework for determining suitable building methods per location.

Requirement ID	Aspect	Sub-aspect	Requirement	Requirement Value Qualitative
Technical				
TE-1011	Structural Building Components	**Strength**	Loading types and loads withstandable by construction	Construction should minimally be able to withstand the constant and variable loads as given by the Building Code
TE-1012	Structural Building Components	**Redundancy**	Presence of redundancy regarding structural elements	Structure should at least allow some redundant elements to relieve structure´s dependency on a single structural element in its imagined form.
TE-1013	Structural Building Components	**Non-structural elements**	Placement and amount of non-structural elements	Non-structural elements should not diminish the inherent properties of structural elements or general safety
TE-1014	Structural Building Components	**Regulated safety**	Level of safety needed in regular usage of building according to building code	If building type is mentioned in the building code then compliance with minimal requirements as stated in most recent version of the Nepali Building Code If not mentioned in building code then according to general structural principles
TE-1020	Seismic Performance	**General seismic performance**	Structure should be able to withstand seismic activity	Combination of aspects TE-1021 - TE-1025 determine the performance during seismic activity, the structure should at least be considered category C according to the Worldhousing.net classification
TE-1022	Seismic Performance	**Diaphragms**	Degree of stiffness of diaphragms	Must allow for diaphragms that can provide ensure a uniform redistribution of lateral loads amongst structural elements

Table 7.1.: Aspects and sub-aspects within 'Technical' main aspect and corresponding requirements

8. Discussion

This chapter will elaborate on the limitations of the results and their consequences for report one. These shortcomings need to be taken into account by readers and future Shock Safe Nepal teams. The discussion points are categorised according to the main subjects that are elaborated in the report.

Introduction Nepal – During the course of more than two months much information has been gathered by the Shock Safe Nepal team; some by research and observation and others in more indirect manners. In creating the general overview we intended to be informative whilst not being overkilling. Due to the time component, information that was incorporated might have become out-dated. It is advised that information is validated by each group and expanded where possible without overloading the reader with information. Another difficult aspect of the given introduction is that deeper layers might be missed due to a lack of experience. The given introduction is very broad and describes the overall situation of construction in Nepal, a consequence of this is that, when looking in to a specific topic, more study is required before further work can be built upon that base. A consequence of these points is that the reader still requires more study to really understand certain topics.

Correctness and experience with zones – The zones used in this report have been partly adopted from the classification of the United Nations programme UN-Habitat. This choice for zoning is not definitive and zones might be added. Given the experiences obtained from two months in the affected parts of Nepal we can say with certainty that these zones do cover much of the load. However when doing research outside of the investigated area the zones might not be applicable due to the diversity of the built environment of Nepal. This creates the limitation that only a small part of the country is documented and validated.

Requirements package validation – At the start of the project the goal was to validate information in multiple cycles, through interviews and questionnaires. However we experienced some difficulty in obtaining the needed information from the questionnaires. The problem was that questionnaires needed to be easy enough to be understood while uncovering all the needed information. In some cases this proved to be too much, the questionnaires were still experienced as too difficult resulting sometimes in unusable or inaccurate data and therefore less reliability. Furthermore due to India's unofficial trade blockade some field trips were not possible due to lack of gas, decreasing the amount of validation.

Building methods – The chosen building methods were preselected on the base of some initial criteria. However some building methods were added after the scope choice of report part two. Therefore the building methods in part one cannot be seen as complete when taking into account the scope of entire Nepal. Addition of more building methods can increase the quality of future researches. The data gathered for each building method is not equally objective for each building method or each aspect per building method, due to different sources. The data might be biased by the writer or by the manufacturer providing the information.

Stakeholders - The stakeholder analysis should be an ongoing process, their power and interest could change in time. Therefore the power-interest grid is a 'snapshot' of that period in time. Stakeholders can enter or exit the context of this report. In the mentioned situations the stakeholder analysis should be updated. The judgement on their power and interest is partly subjective, since power and interest are perceived values based on stakeholder characteristics. Therefore controlling and updating by future teams is advised.

9. Conclusion

The main goal of report one is the assessment of challenges regarding rebuilding Nepal. The report serves as a start-up document for further research by future Shock Safe Nepal teams. The created products cover five aspects that are useful when considering a construction project in Nepal. These products are the general overview of Nepal, a geographical classification including research topics, earthquake engineering principles, an overview of the initially selected building methods, and a general set of higher level requirements applicable for all zones. The conclusions and recommendations are therefore addressed to future Shock Safe Nepal teams and any interested party who is planning construction activities and/or research in Nepal.

General

Nepal is a country that is rich in diversities; from its altitudes to the climatological areas, the religions and the many different ethnic identities. It is a country that is extremely rich when it comes to certain natural beauties, such as the tourist attracting sceneries and culture historic areas. But also very rich in some intangible cultural aspects, such as tight family ties and the complex intertwinement of society. On the other hand it is very poor when it comes to wealth, reliability of infrastructure and stability of the political climate. Many factors contribute to the difficulties and possibilities of rebuilding in Nepal.

The main issues when it comes to rebuilding Nepal consist of existing structural issues and newly formed earthquake related issues. Some of its structural challenges are that Nepal is very much dependent on its neighbouring countries due to its lack of certain natural resources; it is especially dependent of India who serves as the main importing partner for electricity in peak hours, construction materials and petrol. Furthermore it suffers from availability and reliability issues concerning the basic utilities such as the lack of electric capacity leading to load shedding. A lack of quality of infrastructure makes large parts of the country difficult to reach, especially during monsoon season due to heavy rainfall. The earthquakes also have caused some large challenges such as the enormous number of houses that need to be rebuilt causing strain on the availability and costs of materials and labour. The buildings that have survived but still form a risk during future earthquakes need retrofitting. A conclusion which can be drawn after the assessment is that the main problem in rebuilding is not a lack of knowledge regarding earthquake safe construction but rather the implementation of this knowledge. The governmental and knowledge institutions face difficulties in transferring the available knowledge to the homeowners and builders. The available knowledge is thus not always used in the construction sector, forming a problem which is especially noticeable in rural and remote areas. Drafting the new constitution and the new building codes have suffered many delays causing the reconstruction of the country to stagnate. Luckily the resilience and optimistic attitude of the Nepali people enable them to react flexibly and take measures into their own hands by constructing temporary shelters for instance. A downside of this is short term solutions, such as housing made out of all corrugated sheets, turning into long term solutions. Luckily there is a young and ambitious generation of Nepali who are willing to make changes in Nepal.

Summarizing, the main problems of rebuilding Nepal seem organisational, however with a technical and financial background. Research on managerial and technical aspects of the problems should provide outcome for the above mentioned observations.

Combined SWOT

Based on the information retrieved from the literature research, market research, site visits, interviews and meetings in the Netherlands and Nepal several conclusions have been made. These conclusions are given below and are summarised in a SWOT, exposing the strengths, weaknesses, opportunities and threats of rebuilding Nepal. These observations should serve as guidelines for report 2 of team one and future Shock Safe Nepal teams.

Strength

- Financial resources for start of the rebuilding process available, since international funds have been pledged and the government proposed a gift and loan system;
- Financial, material and engineering aid by external parties and or countries to specific villages;
- Worldwide natural goodwill towards Nepal;
- Resilience and optimistic attitude of population with respect to discomforts, such as disaster situations;
- Strong family ties and tight social structures make that people help each other;
- The creativity and ingenuity of people make them adaptable and flexible in certain situations;
- Rich in natural scenery and culture, attracting large scale tourism;
- Many culturally historic values;
- Existing traditional construction methods which are proven to be earthquake resistant to a certain level.

Weakness

- Lack of sufficient financial resources cause dependency on international aid;
- Young democratic political history with climate which is not efficient and decisive;
- Overall lack of consistency and reliability regarding quality of construction material;
- Lack of knowledge on earthquake safe engineering and constructing on execution level;
- Insufficient adequately skilled masons and construction workers;
- Young generation migrates for a better financial situation, construction workers for instance move to the United Arab Emirates for work;
- Little chances of knowledge flowing back from overseas construction workers that gained good experience;
- Lack of equipment, such as machines to remove RCC debris;
- Difficult/mountainous terrain to build on (Himalayas);
- Lack of control on permits and building codes;
- Incremental building (adding of extra or asymmetric stories after completion);
- Buildings often too close to each other; pounding effect during earthquake;
- Lack of certain natural resources causing a great need for import;
- Unbalanced between import and export, billions vs. millions;
- Located on active fault lines making it seismically active;
- Structural challenges concerning the availability of utilities (gas, electricity and water);
- Dependence on neighbouring countries, especially India;
- Many people live below poverty line;
- Educated people move abroad for better living conditions and jobs;
- Heavy monsoon season, harvesting season and many festivals cause a short time slot in which construction is possible;
- Bad infrastructure between and within cities and villages, making many places difficult to reach;
- Heavy rainfall during monsoon destroys much of the weak infrastructure;

Opportunity

- Learning from foreign organisations which provide aid in Nepal;
- Build Nepal back better, prepared for future earthquakes;
- To create more earthquake awareness;
- The infrastructure can benefit from the national reconstruction, resulting in improvement of roads, water, electricity and gas utilities;
- Room for entrepreneurship, better investment climate;
- Possibility to learn new construction techniques that can be embedded or adapted in the culture;
- Large unskilled labour force available that can be utilised for construction;
- Young and ambitious group of young Nepali willing to make changes in Nepal;
- Many unexploited possibilities in the hydropower sector, a natural resource that can be exported;
- More and more educated people, youngest generation largely bilingual;

Threat

- Politically unstable climate is preventing the Nepalese government from forming an executive body in the rebuilding process which is necessary for collecting the pledged international funds;
- Haste in rebuilding (before monsoon and before winter) may have negative influence on housing quality and/or culture historical character;
- People are waiting for the new building codes to be completed before starting to construct since they are afraid to have to 'redo' it or won't get the pledged monetary aid from the government;
- Donated corrugated sheets widely used for housing instead of temporary housing resulting in 'ugly' sight which is not part of Nepalese architecture;
- People unfairly trust non-engineered RCC frame constructions because 10 year old concrete structures that have survived are being compared with 100 year old brick/wood traditional structures;
- An abundance of NGO's, governmental organisations, companies, private persons etc. can make the situation disordered or cause unnecessary overlap of work;
- Diversity of ethnic groups can cause invisible difficulties in the design of houses;
- Diversity of altitudes cause divers climatological zones which increase design challenge;
- The short term orientation of Nepal can cause difficulty in design and execution;
- The large number of houses needing to be rebuilt can have negative effect on the costs and availability of materials and labour;
- Due to much uncontrolled construction lack of supervision and control on non-engineered construction;
- Creativity and ingenuity can be used to 'fix' damaged buildings;
- The large scale need for retrofitting of existing structures to increase safety during seismic activity;
- Temporary shelters and refugee camps may become permanent;
- Many interesting earthquake safe building methods not known in Nepal;

10. Recommendations

The recommendations for report one on further research by future Shock Safe Nepal teams can be divided into:

1. Updating the report sections

As mentioned in the Discussion chapter we advise future teams to update the context overview, building methods, and research challenges. Reasons to do so are:
During the last half year Nepal experienced influential changes to the country, such as the earthquake leaving the country to rebuild, the approval of the first constitution of the country, and an ongoing border blockade. During the documentation of the report probably not all consequences of these events were noticeable. Combined with the changing situation over time it is important to update. Most interesting aspects for the context overview are political situation, construction sector (material availability and cost) and financial aspects. Financial aspects are especially interesting for the building methods.

2. Sharing our knowledge

Future Shock Safe Nepal teams are advised to cooperate with Dutch and Nepalese organizations that on one hand can help the team in its research, but on the other hand is interested in the implementation of the results. Creating a knowledge platform on earthquake engineering is one of the overall goals, sharing this information should benefit Nepal.

3. Solving observed challenges

Solving the existing list of challenges could provide the much needed support in the reconstruction of Nepal and contributes to achieving the goal of Shock Safe Nepal. The challenges are divided into two groups: related to housing zones (A-E) and additional topics.

Zone A:

- Retrofitting or repairing the damaged RCC frames and brick masonry houses
- Rebuilding historical heritage sites
- Control on/building according building codes
- Demolition of severely damaged buildings
- Logistical challenge due to limited space

Zone B:

- Designing feasible low-tech housing
- Unattractive nature of Zone B
- Uncontrolled construction
- **Update urban planning**

Zone C:

- Combining earthquake safe housing while maintaining traditional character
- Maintenance of traditional housing
- **Use of historical artefacts in reconstruction**

Zone D:

- Safely construct on slopes
- **Implementation of different foundation types**
- Design of multifunctional structures (housing / workspace / restaurant)
- Choice of material, transport cost, dependant
- **Implement the use of second-hand material**
- **Implementation of functions for a profession in building types**

Zone E:

- Restore infrastructure
- Distribution of knowledge on earthquake safe building
- Earthquake safe designs with local materials
- **Choice of the correct building sites**

Additional topics

- Waste management
- Clean drinking water in urban areas
- Stable energy provision
- Efficient road network
- Distribution of professional knowledge
- Start-up local entrepreneurship
- Management of local resources (wood, water, soil)

11. Critical review of construction in Nepal

After writing report one we found it necessary to give a critical review on the construction situation in Nepal. It is important to notice that this part is written out of our personal perspective gained in our eight-week site visit.

The earthquakes happened half a year ago and at first sight not much on-going reconstruction is observed. On most of the main roads the debris has been removed and the materials are stacked for re-use. At the more far-off locations the collapsed buildings are still visible and the sites look untouched. At first notice it is not clear what happened with the former inhabitants. At the remote locations the earthquake-affected areas look even more abandoned.

A large part of the population in Nepal lacks the resources to rebuild their house but also the demolition and clearing up of the sites has to be paid by the house owner therefore these issues remain. During our visit we have seen the rebuilding of structures, but almost all of these structures where seen as temporary.

Construction of permanent housing halted because everyone is waiting for the government to distribute the new building code, to which new construction has to comply. People are waiting for the distribution of the relief funds, a requirement for receiving this fund is complying with the earlier mentioned building codes. As students we think the upgrade of the building codes is important for safety of future construction in Nepal, but it is harsh to see the people suffering so long after the real disaster happened.

The main reasons for this delay are the other agenda items of the Government of Nepal, mainly the draft and acceptance of the first constitution was important. In the last period of our stay also the political situation with India forced the government to shift their focus.

Before large-scale reconstruction in Nepal can be initiated all these side issues have to be resolved. This situation shows the lack of political decisiveness needed to rebuild a country in need. It is important for future teams to keep this situation in mind when doing their research in Nepal, but this should certainly not stop you from helping the people of Nepal.

Report Two

Ribbon development in rural areas

1. Introduction

Report one describes five different settlement zones, each with their own characteristics and challenges. In report two one of these challenges is chosen for further elaboration. This report focuses on a challenge seen in the Rural Villages (Zone D), more specifically, the challenges concerning Ribbon Developments in sloped areas. During the research for report one this challenge was experienced as a major problem and was not specific targeted by any of the local organizations.

This type of settlement, the Ribbon Development, consists of a group of houses or buildings that are arranged along the length of the road. These villages are often formed by physical restrictions or attractions that create a linear barrier forcing the village to expand along the line next to the existing buildings creating the prolonged form of the settlement. These barriers can be of geographical or of man-made nature such as rivers, mountain ridges or paved and unpaved roads (Mandal, 2001). Due to consummation of accessible land in the west and the difficulty to develop the east, in the 1980s and 90s the urban growth of Kathmandu was generally occurring in north-south direction. On the main trade routes between the capital and surrounding villages people started to build along the main road forming the Ribbon Developments. An example of this is the intensification of land use for buildings on the route between Kathmandu and Bhaktapur since the 80s. One of the reasons for this urbanisation was the trolley connection between Bhaktapur and Kathmandu (ICIMOD, 2007).

Ribbon Developments are commonly seen along the main routes in Nepal, especially along the North-South orientated trade routes between China and India. Due to the economic growth of the main cities and the increasing accessibility of mountainous areas the Ribbon Developments increase in size. In some cases it develops sufficient size and a distinctive market centre enabling it to attract new buildings behind the initial line of (commercial) buildings, slightly altering the shape of the linear settlement (Singh, 2012). In the earthquake affected area the landscape is very mountainous with winding roads going up mountain slopes. This geological characteristic causes for differences in elevation along a route and the lack of level construction ground resulting in the villages expanding on or against a slope resulting in 'interesting' constructions. These constructions with irregular foundations attract unequal forces during an earthquake resulting in 'weaker' buildings of which many have collapse or are damaged buildings.

Ribbon Developments have certain opportunities. Often they are relatively well accessible by road allowing for supply of materials. They lack historical value or are not targeted by heritage preservation groups or to heritage laws giving a degree of (design) freedom. In this report a design solution will be sought for a specific problem in Ribbon Developments. This will be done by assessing the challenges in this village type, linking these to the earlier uncovered general information given by report one and new, case specific, information.

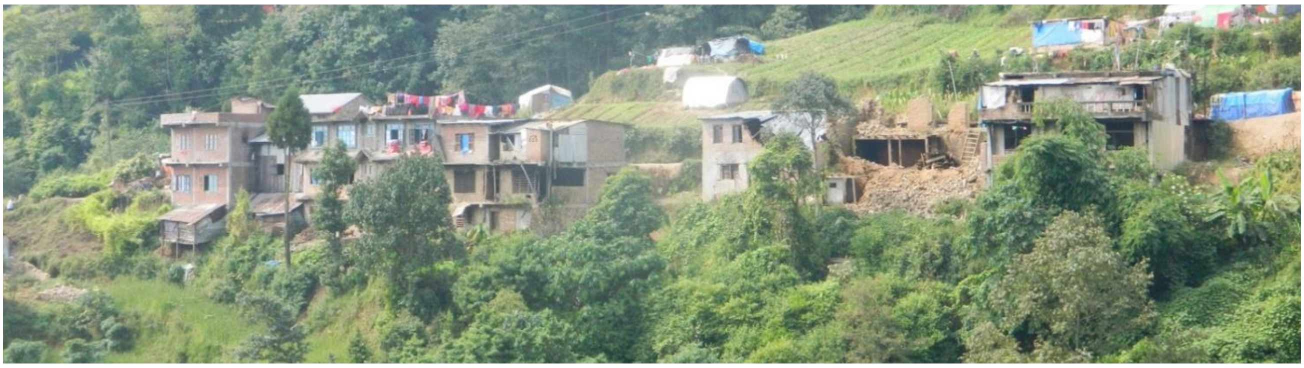


Figure 1.1: Hillside Ribbon Development on the road to Kakani, Nepal (Shock Safe Nepal group 1).

Problem definition

The Ribbon Developed Settlements are observed to face several challenges.

Due to the increasing population in the Kathmandu valley settlements are rapidly increasing in the hilly areas surrounding the valley and the highway corridors (Narayanan et. al., 2012). These highway corridor locations are often commercially favourable for small businesses such as shops, restaurants and workplaces combined with housing increasing their rapid expansion, stimulates the linear shape and reducing the choice for building locations.

The growth of these settlements is often very fast and uncontrolled, most of the areas lack rules and regulations because they are regulated by local village development committees (Kharel et al., 2014 2014). Location, design and construction are often informally decided and executed instead of being engineered leading to more risks being taken than necessary.

Even though there is limited research done on building on slopes in the mountainous areas of Nepal, there is a substantial body of knowledge from other areas indicating several structural vulnerabilities and challenges. Multiple studies indicate that buildings resting on sloping ground are more prone to earthquake damage than buildings resting on flat ground due to unequal stress distributions in the unequal columns (Khadiranaikar, 2014). The commercial functions at road level create a vulnerability due to the before mentioned. And the mountainous locations have an increased risk of extremely destructive land-, rock- and mudslides after earthquakes or heavy rain capable of destroying entire villages.

A combination of these problems creates an interesting problem space which can have different answers. The objective of the report is to find out what the preferred building methods are when constructing earthquake safe housing in Ribbon Developments on sloped ground. From these preferred building methods an initial design is desired to show how these building methods can be implemented. The preferred building method should be technical able to withstand a next earthquake while also meeting social-cultural and functional requirements of the local people. Finally the resources should be available to construct the building in a sustainable and financially feasible manner.

Research question

This problem definition leads to the research of preferred building methods when constructing earthquake safe housing in rural areas, more specifically in Ribbon Developments on sloped ground, resulting in the following research question:

What are the preferred post-earthquake reconstruction solutions, which are bound by social-cultural, financially feasible, technical, resource, functional and sustainable requirement aspects, which can be representative for all ribbon developed settlements in post-earthquake Nepal?

2. Methodology

The following methodology is used to answer the research question, which followed from the problem definition.

The information from report one will be elaborated on the rural village settlement typology. With the help of observations and feedback sessions with local experts an extended SWOT analysis focussed on ribbon development in the rural village settlement typology will be made. With the information from this SWOT analysis the overall requirements for construction in Nepal, made in report one, will be altered and elaborated to correspond to the requirements needed for construction in ribbon development in rural village settlements.

The minimum requirements for construction in rural village settlements will be determined by interviews and questionnaires, from which the results are compared with the literature and observations of the project team. The list of minimum requirements will be used to span the solution space for ribbon development.

Each building method will be scored according to the set requirements; this will be done using a one-to-five scoring method to give qualitative values. The scored building methods will be plotted in the solution space to exclude the building methods that do not fit the desired requirements.

A Multi Criteria Analysis (MCA), with weighting factors determined by combining the local preference with the technical demand, will rank the remaining building methods on preference to define the most desirable solutions. To ensure the weight factors are correct a sensitivity analysis with different scenarios and viewpoints will be performed, resulting in a short-list of building methods fit for and preferred in the chosen settlement type.

One building method out of this short-list will be further elaborated, without providing structural validation. The focus point for the design will follow from solution space definition and will be proposed in a conceptual preliminary design. The design based on the case village should serve as a conceptual solution for the entire settlement type. The result will form the input for the recommendations for further research.

Scope

To keep the project manageable a scope is determined. The scope of report two is limited to ribbon development in the rural settlement type with as focus point 'construction on the downhill side of the slope'. The list of building methods that are described in report one form the basis for report two, this list will not be extended. Also the amount of requirements which span the solution space are limited to the information described in the building methods since it is not possible to assign values to a requirement when the required information is not available. The list of MCA requirements is limited to minimise dependencies between requirements and to identify a clear distinction between the accepted building methods. By this limitation larger percentages are distributed to the chosen requirements and larger differences will be shown.

Because of the changing political situation it is not found feasible to come up with reliable data on the cost perspective of the building methods. The relative costs between building methods will be based on a ranking.

3. Elaboration on case village

To gather data on ribbon developments, a case village is chosen that fits the requirements and challenges as described in the problem definition, being:

- Village is a ribbon development, with possible parallel building rows behind the initial line;
- Buildings are built on slopes;
- It is situated on a main road giving commercial and economic characteristics;
- It shows signs of expansion e.g. construction, lively streets.

3.1 Location

As can be seen in figures 3.1 and 3.2 Dhunche is situated just outside the valley to the north of Kathmandu. It lies on a main route to the Chinese/Tibetan border, making it a busy route with economic and commercial characteristics. The village is located at the main road between Kathmandu and Tibet in the lower regions of the Himalayas. The mountainous terrain limits the amount of flat construction sites resulting in building being constructed on slopes and leaning against the road.

Figure 3.1: Dhunche on national scale, (Maps.google).

Figure 3.2: Dhunche on a local scale (Maps.google).

3.2 Demography

Dhunche is part of a Village Development Community and capital of the Rasuwa district. In 2001 the village population was 2330, with a total number of households of 504. Two-third of the population is Buddhist and one third is Hindu (Nepal Census Data 2011). Later data is not available but during the site-visit many newly constructed buildings where seen.

3.3 Function

Dhunche is often used as a 'mountain station', for distribution to the higher mountains and as a base of departure for companies who work in the higher mountains e.g. NGO's. Being one of the last larger settlements on this road through the mountains, it often functions as a start or end point for recreational hikes. For these two reasons a number of hotels and lodges are seen in Dhunche.

3.4 Built environment

The built environment and infrastructure showed some characteristics which can of interest. These have been divided in the following categories, building characteristics, layout of main road, utilities and accessibility. On building level it is seen that most of the buildings have commercial or profession related spaces on the road level floor. Many of the buildings are not limited to single storeys but often range between two to five storeys, with some exceptions exceeding these numbers. The layout of the main road is lacking, resulting in no clear functions defined on the road. The road has certain dimensions which are bounded by the buildings and private territories. This limited road width serves multiple functions such as stalls for shops, tables for restaurants, pedestrians, parked vehicles, local traffic and traffic that is passing through the village. The utilities in Dhunche are similar to other villages in Nepal, power is fed to houses by cables. Water is guided into the village from natural springs and is publically accessible from several points by means of a well or faucet. It is also seen that some of the wealthier households have water tanks on their roofs and water supply is more integrated in the building. The accessibility of Dhunche is heavily depended on the weather conditions, in good weather conditions the village can be reached within a day’s drive from Kathmandu. While during the monsoon season there is much chance that parts of the road are impassable due to heavy rainfall, the road being washed away or landslides

that have destroyed the road. The differing accessibility of Dhunche has implications on the supply of construction materials making it very difficult to have a reliable logistic route.

Figure 3.3: Dhunche okt 2012 by Yarda Volsicky (maps.google)


Figure 3.4: Dhunche okt 2012 by Yarda Volsicky (maps.google)

3.6 Post-earthquake situation

The situation of Dhunche almost half a year after the earthquakes still shows signs of the earthquakes on the built environment. Gaps in the line of buildings, tent camps, damaged buildings, much sheet metal used in many different ways and (abandoned) construction sites. The new buildings being constructed appeared to be mainly RCC frame structures, while repairs were often done to other building types.

To confirm the ribbon development characteristics and to gather more data two other ribbon developments were visited. The additional villages are Kakani and Panga, respectively north and west of Kathmandu. The villages, even though not outside the Kathmandu Valley showed similarities to Dhunche. The inhabitants are forced to build on a slope, numerous ground floors have commercial functions, reconstruction is happening mainly with RCC frames and street layout is very similar with passive, active, slow and fast traffic on the same road. The information gained from these case villages will all be combined to form the base for the following steps.

Figure 3.5: Construction site in Dhunche (Shock Safe Nepal group 1).

Figure 3.6: Buildings on a slope in Dhunche (Shock Safe Nepal group 1).

4. SWOT for case village

To find out what the preferred building methods are for the case village Dhunche, the strengths, weaknesses, opportunities and threats are determined. This is done by building upon the existing information from report one and adding to this the gathered information during the site visits, interviews and literature research done for the case village. This results in the following SWOT table. The SWOT is the basis to determine the requirements and the design of the solution.

Strength:

- Presence of commercial functions result the availability of financial resources for the start of the rebuilding process
- Financial, material and Engineering aid by external parties and or countries to specific villages;
- Resilience and optimistic attitude of population with respect to discomforts, such as disaster situations;
- Strong family ties and tight social structures make that people help each other;
- The creativity and ingenuity of people make them adaptable and flexible in certain situations;
- Rich in natural scenery, attracting large-scale tourism;

Opportunity:

- Learn from foreign organisations providing aid in Nepal;
- Build back better, prepared for future earthquakes;
- To create more earthquake awareness;
- The infrastructure can benefit from the national reconstruction, resulting in improvement of roads, water, electricity and gas utilities;
- Room for entrepreneurship, better investment climate;
- Possibility to learn new construction techniques that can be embedded or adapted in the culture;
- Large unskilled labour force available that can be utilised for construction;
- Young and ambitious group of Nepali willing to make changes in Nepal;
- More and more educated people, youngest generation largely bilingual;

Weakness:

- Lack of sufficient financial resources cause dependency on international aid;
- Lack of appropriate building sides because of hilly character;
- Overall lack of consistency and reliability regarding quality of construction material;
- Lack of knowledge on earthquake safe engineering and constructing on execution level;
- Insufficient skilled masons and construction workers;
- Lack of equipment to remove RCC debris;
- Difficult/mountainous terrain to build on (Himalayas);
- Part of a VDC resulting in Lack of control on permits and building codes;
- Incremental building (adding of extra or asymmetric stories after completion);
- Buildings too close to each other; pounding effect during earthquake;
- Lack of certain natural resources causing a great need for import, policy on cutting trees;
- Close to the active fault lines making it a seismically active region;
- Structural challenges concerning the availability of utilities (gas, electricity and water);
- Heavy monsoon season, harvesting season and many festivals cause a short construction time slot;
- Bad infrastructure between and within cities and villages, making many places difficult to reach;
- Heavy rainfall during monsoon destroys much of the weak infrastructure;

Threat:

- Politically unstable climate is preventing the Nepalese government from forming a executive body in the rebuilding process and collecting the pledged international funds;
- Haste in rebuilding (before monsoon and before winter) may have negative influence on housing quality and/or culture historical character;
- People are waiting for the new building codes to be completed before starting to construct since they are afraid to have to 'redo' it or won't get the promised monetary aid;
- People unfairly trust non-engineered RCC frame constructions because 10-year-old concrete structures that have survived are being compared with 100-year-old brick/wood traditional structures;
- Diversity of ethnic groups can cause invisible difficulties in the design of houses;
- The short-term orientation of Nepal can cause difficulty in design and execution;
- The large number of houses needing to be rebuilt can have negative effect on the costs and availability of materials and labour;
- Due to much uncontrolled construction lack of supervision and control on non-engineered construction;
- The large-scale need for retrofitting of existing structures to increase safety during seismic activity;
- Temporary shelters and refugee camps may become permanent;

5. Solution space

The solution space method is used to find out which building methods are suited for the earthquake safe rebuilding in ribbon developments in Nepal. This is determined by setting the harder and crisper boundaries of a solution based on minimum requirements. In the chapter the applied method will be explained and the results will be given.

Definition

According to Wasson the definition of a solution space is: “A bounded abstraction that represents a capability and level of performance that, when implemented, is intended to satisfy all or a portion of a higher level problem space.” (Wasson, 2005). Translated to this project the solution space will be a list of higher-level requirements to which a building method in a ribbon development should minimally comply.

5.1 Requirements

The problem space consists out of a number of higher level requirements which have been systematically defined for housing in Nepal. The full list of requirements can be found in Appendix 1.C general requirements Nepal.

Requirement ID	Aspect	Sub-aspect	Requirement
Technical			
TE-1011	Structural Building Components	**Strength**	Loading types and loads withstandable by construction
TE-1012	Structural Building Components	**Redundancy**	Presence of redundancy regarding structural elements
TE-1013	Structural Building Components	**Non-structural elements**	Placement and amount of non structural elements
TE-1014	Structural Building Components	**Regulated safety**	Level of safety needed in regular usage of building according to buildingcode

Figure 5.1: General requirements specifications Nepal (Shock Safe Nepal group 1)

The defining of a solution space is not a one-time task but an iterative process with feedback loops and validations. For the creation of the requirements specification corresponding to the Ribbon Development a similar approach is applied by expanding the general requirements specification with the data retrieved from the various inputs. The results are requirements applicable to Ribbon Developments in rural areas. To keep the requirements measurable at this level of abstraction they are elaborated into qualitative values. These Ribbon Development requirements can be found in 2.A: General requirements ribbon development. These requirements should be considered when designing solutions for a similar location.

TE-1011	Structural Building Components	**Strength**	Loading types and loads withstandable by construction	Construction should minimally be able to withstand the constant and variable loads as given by the Building Code
TE-1012	Structural Building Components	**Redundancy**	Presence of redundancy regarding structural elements	Structure should atleast allow some redundant elements to relieve structure's dependency on a single structural element in its imagined form.
TE-1013	Structural Building Components	**Non-structural elements**	Placement and amount of non structural elements	Non-structural elements should not diminish the inherent properties of structural elements or general safety
TE-1014	Structural Building Components	**Regulated safety**	Level of safety needed in regular usage of building according to buildingcode	If building type is mentioned in the building code then compliance with minimal requirements as stated in most recent version of the Nepali Building Code If not mentioned in building code then according to general structural principles

Figure 5.2: General requirements ribbon development (Shock Safe Nepal group 1).

5.2 Scoring

The initial 47 requirements are slimmed down to maintain an overview and keep the project manageable. This selection is made based on the degree of importance of a certain specification and the information available for each building method elaborated in report one. The final list of requirements to be used for spanning the solution space is 31 requirements. These requirements will be used in determining if a building method is fit for the given context.

To determine if a building method meets a requirement a quantitative score is needed. For all the requirements a one-to-five scoring method is used, with a one as the lowest possible value and five as the highest possible value. It is important to notice that the one-to-five scoring method is not a ranking but a category into which the building method is placed; therefore not all the categories/values can or have to be answered. The scale values per requirements can be found in Appendix 2.B: Explanation of values.

Requirement Value Qualitative

If building type is mentioned in the building code then compliance with minimal requirements as stated in most recent version of the Nepali Building Code
If not mentioned in building code then according to general structural principles

Explanation Scale

1= Not in building code and not according to general structural principles
2= Not in building code and doubtable to fit general structural principles
3= Not in building code but acceptably according to structural principles
4= In building code with thumbrules and limitations on design
5= In building code and according to structural principles

Figure 5.3: example of qualitative value and scale explanation (Shock Safe Nepal group 1).

The explanation of the requirement is made as clear as possible, for some scales it is crisp due to the possibility of quantitative assessment, while for others it is only possible to give qualitative explanations. To clarify the reasoning behind the scores a short explanation of the scores is given in Appendix 2.F: Explanations of building methods scores.

2	
2	The bonding in low strenght masonry and adobe increases the probability of partial colapse when part of the structure is damaged. The structure is otherwise redundant because the wall is load bearing in its whole.
2	
3	
3	The use of cement mortar creates a stronger bond between brick, decreasing the probability of collapse when some bricks are removed from the whole. In the case of interlocking bricks it is the locking mechanism that creates a strong bond between the bricks.
3	
3	

Figure 5.4: explanation scores building methods (Shock Safe Nepal group 1).

The information needed to score the building methods on the each requirement is given in the overview of building methods out in report one, the literature study, observations and interviews are combined into a general informative document. An overview of all the scores given to each requirement and for each building method is given in Appendix 2.C: Overview scores building methods.

		Minimum values	Brick masonry in cement mortar	Confined masonry	Hollow concrete brick masonry	Reinforced Cement Concrete Frames
Functional						
	Amount of storeys	2	3	5	3	5
	Possibilities	3	3	5	3	5
	Opportunity	3	3	3	3	5
	Elements	3	4	4	4	4
	Safety	3	4	4	4	4
	Possibilities	2	4	4	4	5
Sustainable						
	Re-usability	1	2	2	4	2
	Recyclability	1	2	2	2	2
	Impact	2	3	3	3	3
	Self-sustainable	2	4	5	3	5

Figure 5.5: part of scoring building methods overview (Shock Safe Nepal group 1).

5.3 Minimum values

The six aspects and their underlying 34 specification requirements span the solution space. To bind the solution space for each requirement minimum values are determined in a group workshop, each participant independently gives their input and the deviating values are discussed during the workshop. The minimum values from the workshop are subjected to a sensitivity analysis, this is done to determine if the chosen values were considered to be acceptable. Values that show unanticipated results are discussed and reconsidered according to the scoring method.

The sensitivity analysis showed changes in the minimum values of seven requirements:

- Technical Aspect: the minimum values of Seismic performance, Improved Seismic Performance, Sensitivity to Surface and Maintenance Reliability are increased by one.
- Resources Aspect: the minimum value of Material Quality and Technical Period are increased by one.
- Feasibility Aspect: the minimum value of Use of Local resources is increased by one.

Category		Minimum values
Technical		
Building components	*Redundancy*	2
	Building code	3
Seismic Performance Standard	*Performance*	3
Improved Seismic Performance	*Possible*	4
Sensitivity to surface	*Foundation resources*	2
Climate	*Openings*	2
	Thermal	2
Life span	*Lifespan*	3
Maintenance	*Reliability*	3
	Maintainability	2
Complexity	*Ease of learing*	2

Figure 5.6: example of minimum values (Shock Safe Nepal group 1).

The final list of minimum values for the solution space can be found in Appendix 2.C: Overview scores building methods.

5.4 Filtering by solution space

All the building methods are filtered by the boundaries of the solutions space, determined by the minimum values of each requirement. In Appendix 2.C.: Overview scores building methods the points where a building method does not meet the minimum requirements are marked in red. In some cases it may be wise to make an exception due to the minor lacking's of a building method.

The overview on the next page clarifies which building methods are accepted, excluded or passed by exception. For each category the above average and below average values are explained giving insight into the decision.

Accepted Building methods

1c. Stone masonry in cement mortar / 1d. Brick masonry in cement mortar

Stone and Brick masonry in cement mortar score exceptional on the experience available and the architectural embedding; they score just acceptable on maintenance, amount of storeys and expandability.

1e. Hollow concrete brick masonry

Hollow concrete brick masonry scores average to good on all sub-aspects.

1f. Reinforced Cement Concrete Frames

RCC frames score well on improved seismic performance, the reliability of maintenance, adaptability, the number of storeys and the expandability. They score just acceptable on maintainability, use of national resources, and re-use and recyclability

2e. Concrete in-situ shear wall

Shear walls are quite comparable to RCC frames, however it scores just acceptable on expandability and labour intensity due to entire walls that need to be reinforced.

2f. Confined masonry

Confined masonry is quite comparable to RCC frames and Concrete in-situ shear walls.

3d. Light Weight Steel Profile Building Systems

This building system scores very good on improved seismic performance, maintenance, the technical building period, the national benefit and recyclability. It scores just acceptable on the amount of storeys and the price ranking

3e. Prefab-framed in-situ concrete

Prefab framed in-situ building systems score well on seismic performance, the reliability regarding maintenance, national benefit and the amount of storeys. It scores just acceptable on maintainability, the presence of experience regarding building, price ranking, the use of local resources and the recyclable ness.

Excepted building methods

These are accepted with a remark due to minor lacking requirements.

1g. Timber construction

The timber frame building method would be excluded based on that timber is expensive and not very abundant due to anti deforestation programs. Thus require import from countries such as China, India or Russia. This creates a dependency and limits the stimulation of local and national economy. An exception is made for the method based on that timber is seen as one of the top materials to build with in earthquake sensitive areas and thus is an interesting method to consider. A side note can be made regarding the subsidizing of timber by the Nepali government as a solution.

2b. Dhajji Dewari

The Dhajji Dewari building method would be excluded on the fact that it is difficult to expand vertically and it offers little possibilities for large openings required for workspace due to the many timber braces. An exception is made because it resembles the traditional building styles and performs well in seismic active areas. A side note will be made regarding the possibility of using Dhajji Dewari in the surrounding houses instead of the ribbon-developed houses.

2d. Steel

The structural steel frame building method would be excluded based on that structural steel profiles are not produced in Nepal and thus require import from countries such as China or India. This creates a dependency and limits the stimulation of local and national economy. An exception is made for the method based on that steel is seen as one of the top materials to build with in earthquake sensitive areas and thus is an interesting method to consider. A side note can be made regarding the subsidizing of steel by the Nepali government or the business potential of local steel production as a solution.

3c. Interlocking bricks

The interlocking bricks system requires a perfectly level foundation for the blocks to be placed in a structurally correct manner, creating a foundation this accurate on a hillside requires much extra resources. Based on this the method would be excluded but the interlocking brick scores good on other aspects and appears to be a promising method. For these reasons an exception is made with the side note that the foundation must be engineered in such a manner that it is easily reproducible and reliable.

3f. Single Panel Walling System

The single panel walling system would be excluded based on the requirement criteria regarding expandability, however an exception can be made here. In its standard form the method does not (optimally) allow for vertical expansion, but it could be engineered in such a manner that the building method could allow for vertical expansion.

Excluded building methods

1a. Low strength (stone) masonry / 1b. Low strength (brick) masonry

Low strength stone and brick masonry fail to make the selection due to bad seismic performance, the expandability and the opportunity for workspace with respect to the context.

2a. Adobe / 2c. Rammed earth

Both Adobe and Rammed earth fail to make the selection due to bad seismic performance, the amount of maintenance required, the amount of storeys, possibilities for vertical expansion and workspace with respect to the context.

3a. Bamboo

Bamboo fails to make the selection due to its short lifespan and amount of maintenance required.

3b. Earthbags

Earthbags fail on their proven seismic performance, the amount of storeys, the possibilities for vertical expansion and workspace with respect to the context.

Side notes

Because of limitations on the information on the price label these values are formulated as a ranking between the building methods. For the requirements that belong to the social/cultural aspect the boundary is defined by a combination of cultural adaptability and architectural embedding, a building method needs to fail on two of the requirements before the solution space excludes it. This combination is made because failing on one of the requirements can be overcome by good performance on one the other requirement. The same applies for maintenance, where a building method that scores poorly on both reliability and maintainability will be excluded from the solution space. Whereas if only one of these requirements is not met, the other one can compensate with a good score e.g. a building with very expensive or specialised maintenance but with almost no need for maintenance in its intended lifespan can still be an interesting option.

5.5 Conclusion

The solution space divides the possible from the available building methods based on a reasoning of quantitative values. Some building methods are excluded from the solution space but are still considered valuable for the MCA since there is only one failing value to overcome, these building methods, the exceptions, are included with a side note. The final list of building methods that are fit for the Multi Criteria Analysis belong to the groups of the Accepted and Exceptions.

6. Multi criteria analysis

To find out which building methods are best suited for rebuilding in a ribbon development in Nepal the building methods that passed the solution space are subjected to a Multi Criteria Analysis. The following chapter explains the theory and reasoning behind the MCA resulting in a shortlist of suited building methods.

6.1 Theory on MCA

A Multi Criteria Analysis is a decision-making tool, helping the decision maker. It establishes preferences between options by referring to a specific set of objectives. To do so measurable criteria are required to measure to which level the objectives are met (Communities & Committee, 2010). The London Department for Communities and Local Government describes the follow steps:

1. What objective should be represented by the MCA
2. Identify options
3. Identify criteria
4. Analysis of the options: describe the performance of each of the options for all aspects
5. Weighting: assign weights for each of the aspects to reflect importance of the decision maker
6. Combine the weights and scores to derive an overall value (also include a performance matrix)
7. Examine the results
8. Perform a sensitivity analysis in order to suggest changes in scores and weights: changing weights of the aspects in order to see the change or consistency in output, changing the weights should be done based on a different point of view (stakeholders for instance). Changing the score based on different future scenarios can show the relevance of the future of a certain aspect.
9. Create possible new options that might be better than the originals: Comparing pairs of options might create new options. For example the most beneficial option with the least costly one may show how to combine and create a new option. New options should be added to the list and be awarded a score on all aspects.
10. Making the choice: is eventually a case of judgement. It may be decided a further options or options should be considered and the analysis should be revisited.
11. Feedback

6.2 Objectives and purpose

Every MCA is executed from a certain point of view, for this MCA the viewpoint is those of a consultant. The viewpoint aims at providing data to choose the proper building method(s) that realises multiple goals. It should not only withstands a future earthquake, but should also safeguards cultural and environmental aspects of Nepal while considering the available resources and financial options. The targeted group is the Nepalese house owner who is forced to rebuild their house on slopes located in ribbon developments. The solution should be long-term and be considered the best option on both national and local scale. A MCA often has multiple objectives to take care of, given the viewpoints. For this MCA the following objects have been chosen, consisting of an immediate and ultimate objective. The immediate objectives is the provision of housing for affected people and the ultimate objective is the safeguarding of cultural and architectural values, while national resources are used accountability aiming at an overall safe structural built environment

The purpose of this MCA is to generate a short-list of preferred building methods that serve the objectives and viewpoint.

6.3 Selection of building methods

The selected building methods for the MCA are those remaining after filtering by the solution space. The building methods for which an exception was made by passing them even though a failure occurred in one of the requirements will be monitored. In case one of these exceptions would end up as a preferred building method, the remarks that were presented in chapter 5 should be focus points in the initial design.

Scores

All building methods selected for the MCA were assigned scores on each requirement. The scores of the Solution Space are also used for the MCA. All scores are processed in a so-called Performance Matrix that gives an overview of all performances of the building methods on all aspects and requirements. The Performance Matrix assists analysing dominance and/or similar scoring.

Weights

To give weights to the six aspects of the MCA, which are the same as the Solution Space, an anonymous survey is performed, the results of this survey are analysed to identify outliers and incorporated in the weighting. The individual weights reflect the weights team members of Shock Safe Nepal assigned independently to each aspect. Great similarities and consistency of viewpoint is seen amongst the team members except for one student who assigned quite a different score for the aspects Functional and Technical. Respectively this only produced a 2,75% and 2,25% deviation in the total scoring. The overall consistency was enough reason to use the average of weights for the MCA, as can be seen in table 6.2: combined average weights.

To validate the weights Nepali engineering students were asked to answer the same survey. It seemed their answers were consistent to each other, however more focussed on Resources and Sustainability. While the Shock Safe Nepal team appeared to have a bigger focus on Functionality and Feasibility. Both teams of engineers agree on the relevance of the aspects Technical and Social-Cultural. In the sensitivity analysis it will be assessed whether it is justifiable to combine the viewpoints or keep them separated, as two scenarios.

Weights to the requirements (sub-weights) were assigned based on the 'better than' approach, in which requirements firstly were ordered by a ranking visualized as 'a2>a1>a3'. Based on the drafted viewpoint, the knowledge gained by interviews and a systematic approach the weights are assigned values. All weights are subjected to a sensitivity analysis after assigning all values per requirement. The main weights and sub-weights are shown in table 6.2 : Final weights

Since the main topic is earthquake engineering, seismic performance (standard and additional) is considered to be one of the most important requirement to compare building method on. For Resources, Functional and Sustainable the sub-weights are assigned equally over each pair of requirements, since they are considered to be equally important. Within the Feasibility aspect the price label is assigned more weight, this requirement is considered more relevant from the point of view of a house owner.

Sensitivity Analysis

The weights should be assessed for each aspect to make sure they reflect its importance, this should also be done based on the scores received from the MCA. If mutual differences are small, the weight should be decreased since it concerns a less relevant requirement. The numbers assigned as score should represent the ratio of valuation of the differences according to the preference. After analysing the scores feasibility received less weight, since the scaling of the price label is based on a ranking and not the actual price per m². Also based on the scores resources is considered to be more important for the MCA than the functional requirements.

After analysing the weights by the sensitivity analysis the combined weights represents the desired viewpoint as described above, shown in Table 6.1. The final weights used in the MCA represent engineers from the Netherlands and Nepal, which is a representative group giving the weights some reliability. The final weights are found in table 6.2: final weights

Scoring subjects	Building Aspects					
	Resources	Functional	Technical	Feasibility	Sustainability	Social Cultural
Nepali Engineers	22%	13%	27%	12%	15%	12%
SSN	16%	19%	24%	19%	8%	14%
Average	19%	16%	25%	15%	12%	13%

Table 6.1: combined average of Nepali Engineers and SSN

Average weight (%)	Aspect Code	Sub-weight	Category	Unit
Technical				
25%	TE-1020	30%	Seismic Performance Standard	Performance
	TE-1026	20%	Improved Seismic Performance	Possible
	TE-1031	20%	Foundation	Performance
	TE-1032	15%	Life span	Lifespan
	TE-1061-1062-1063	15%	Maintenance	Reliability
				Maintainability
				Availability
Resources				
19%	RE-2012-2013-2014	50%	Material	Availability
	RE-2021-2022	50%	Labour	Experience
Feasibility				
15%	FE-3011	60%	Price Label	Ranking
	FE-3021-3022	40%	Local economy	Use of local resources
			National economy	National benefit
Social / cultural				
13%	SO-0203	100%	Social/ cultural	Adaptability
			Architectural embedding	Embedding
Functional				
16%	FU-5011	50%	Building height	Amount of storeys
	FU-5012	50%	Expandability	Possibilities
Sustainable				
12%	SU-6011-6012	50%	Recyclable	Reusability
				Recyclability
	SU-6021	50%	Environmental	Impact

Table 6.2: Final weights

6.4 Scenarios

In order to find a building method that is robust and time proof possible future scenarios are taken into account. These scenarios are chosen because they are realistic enough that they might occur and extreme enough to have a big consequence on the rebuilding of Nepal. The four scenarios that are chosen are the current scenario, a no subsidy scenario, a subsidy scenario and the full material availability scenario. These scenarios are considered relevant because of the instable political situation Nepal is in. The following paragraphs will elaborate on the four scenarios

Scenario 1: baseline

The baseline is the context in which Nepal was during the time of writing and for which the building methods have been scored.
Due to the landlocked character of Nepal it has always been dependent on China and India for certain materials and non-material help. Scenario 1 assumes there is some dependency on the neighbouring countries making material availability limited.

Scenario 2: no subsidy

Scenarios 2 and 3 are based on the pledge done by the Nepalese government to provide gifts and loans for house owners that are rebuilding their house. However there is still much debate around if, how and how much money is going to be distributed among the affected people. Scenario 2 takes into account that the government budget is negligible, which results in more expensive measures to become less feasible.

Scenario 3: subsidy

Scenario 3 describes the context in which pledged gifts and loans will become available for households into such extent that feasibility should be less of an issue.

Scenario 4: full material availability

Nepal deals with difficulties regarding availability of construction material. Anno 2015 this problem is additionally complicated due to the oil crisis caused by roadblocks at the Indian border and blocked roads to China due to the earthquakes. This scenario describes the context in which construction materials all are available. This increased availability can have multiple causes of which the most interesting one is based on a reference from Japan where the government subsidised steel as an earthquake safe building material for housing projects.

6.5 Scaling

Local scaling is used to scale all scores; it assigns a score of 0 to the option scoring the lowest on a certain requirement, 100 is assigned to the option scoring highest. Since all building methods selected for the MCA passed the solution space we consider all methods to be sufficient. Therefore we consider the Solution Space score that would be insufficient to be the minimum of the scale. The maximum of the scale is the score of the best performing building method.

6.6 Ranking

Since quantitative measures are used to rank qualitative aspects all building methods are grouped according similar percentages. Analysing performances of building methods in all scenarios shows Reinforced Concrete Frames performs best in multiple contexts. This is not surprising since this building method is widely used in ribbon development settlements; however do not per se excel in technical performance. Rankings differ depending per scenario, interesting to see is Reinforced Concrete Frames, Confined Masonry, Concrete in-situ shear walls, Dhajji Dewari, Prefab-framed in-situ concrete are performing constant in each scenario. Timber and Steel become considerable options in the scenarios 'subsidy' and 'material availability', since their low score on Feasibility and Resources becomes compensated. In the 'no subsidy' scenario building methods that require mainly local resources score better.

Since the final rankings are based on 6 aspects, the Scoring Card Method is used to show excellence on single aspects and to avoid 'the flaw of averages'. These 'aspect rankings' are analysed to conclude whether the overall performance is based on outliers or average good performance. It should be considers whether outliers, positive as well as 'negative', are desirable. The end ranking could generate good performing building methods either by an average of outliers or an average of overall good performance. To make sure the preferred building methods are not a result of the flaws of averages each aspect is analysed and compared to each other.

"Baseline" Scenario	
Score (%)	Building method
71%	Reinforced Cement Concrete Frames
69%	Stone masonry in cement mortar
67%	Confined masonry
66%	Steel
65%	Concrete in-situ shear wall
64%	Timber construction
63%	Light Weight Steel Profile Building Systems
61%	Brick masonry in cement mortar
59%	Hollow concrete brick masonry
57%	Interlocking bricks
57%	Single Panel Walling System
53%	Prefab-framed in-situ concrete
52%	Dhajji Dewari

Table 6.1: Ranking "baseline" scenario (Shock Safe Nepal group 1).

"Subsidy" Scenario	
Score (%)	Building method
71%	Reinforced Cement Concrete Frames
68%	Steel
67%	Stone masonry in cement mortar
67%	Confined masonry
66%	Concrete in-situ shear wall
66%	Timber construction
64%	Light Weight Steel Profile Building Systems
59%	Brick masonry in cement mortar
57%	Hollow concrete brick masonry
56%	Single Panel Walling System
55%	Interlocking bricks
55%	Prefab-framed in-situ concrete
51%	Dhajji Dewari

Table 6.2: Ranking "Subsidy" scenario (Shock Safe Nepal group 1).

"No Subsidy" Scenario	
Score (%)	Building method
74%	Stone masonry in cement mortar
72%	Reinforced Cement Concrete Frames
68%	Confined masonry
67%	Brick masonry in cement mortar
65%	Hollow concrete brick masonry
64%	Interlocking bricks
63%	Concrete in-situ shear wall
61%	Light Weight Steel Profile Building Systems
59%	Single Panel Walling System
59%	Steel
57%	Timber construction
56%	Dhajji Dewari
50%	Prefab-framed in-situ concrete

Table 6.3: Ranking "no subsidy" scenario (Shock Safe Nepal group 1).

"Material Always Available" Scenario	
Score (%)	Building method
72%	Reinforced Cement Concrete Frames
71%	Confined masonry
70%	Steel
70%	Timber construction
67%	Light Weight Steel Profile Building Systems
66%	Stone masonry in cement mortar
65%	Concrete in-situ shear wall
63%	Brick masonry in cement mortar
58%	Hollow concrete brick masonry
57%	Interlocking bricks
56%	Single Panel Walling System
56%	Prefab-framed in-situ concrete
55%	Dhajji Dewari

Table 6.6: Ranking "material always available" scenario (Shock Safe Nepal group 1).

The following section explains, based on the MCA, which highest scoring building methods are interesting for further research and design. Eventually a concept design of one of the preferred building method will be proposed.

- Stone masonry in cement scores high on the end ranking for all scenarios, however scores one of the lowest for the technical aspect. Even though technical has the biggest weight it is still possible to score high on the end ranking, we could call this the flaw of averages. Since we consider the technical aspect to be one of the leading aspects it is considerable to not select 'Stone masonry in cement' as one of the preferred building methods.

- RCC Frames however scores high on the end ranking in all scenarios end has no serious negative scores on individual aspects. The only downside on RCC frames is the score on sustainability, however this could be accepted since this is the aspect with the smallest weight. Besides that its score passed the solution space and therefore satisfies the criteria.

- Somewhat comparable to RCC Frames, confined masonry scores high on all scenarios, with only one of the least performing scores on sustainability. Confined masonry is an interesting method since the used materials is already commonly used in ribbon developments.

- Steel has high scores on all scenarios except the "no subsidy" scenario, which is accountable to the high costs. Also for the solution space steel 'flunked' on the feasibility aspect however was decided on to pass with a remark. When there is a solid strategy to handle the resource and financial challenges steel is an interesting building method, especially because it is one of the best performing methods on the Technical aspect.

- Timber shows the same pattern as steel; high scores on all scenarios except for "no subsidy". Timber passed the solution space with a remark on material availability, since wood is scarce. Timber in general is an interesting method, however large scale application would cause complications on availability, especially due to cutting permits and anti-deforestation programs

Comparison in Pairs

Aspect ranking can also be used to compare pairs of options to possible create new options (hybrid building methods). Table 7 shows the scoring card method, illustrating best performing building methods on each aspect. Best performing methods in the scoring card are compared to each other and the overall highest scoring methods described in the former chapter. RCC frame is compared to the best technical methods: timber, steel, and concrete in-situ shear walls. Since timber is not an obvious combination for RCC, steel and concrete shear walls remain as options. As the following chapters will describe it actually offers an interesting hybrid.

Building method	Technical	Resources	Feasibility	Social Cultural	Functional	Sustainable	Total
Reinforced Cement Concrete Frames					1		1
Stone masonry in cement mortar		1	1				2
Timber construction	1					1	2
Steel	1				1		2
Concrete in-situ shear wall	1						1
Confined masonry					1		1
Light Weight Steel Profile Building Systems						1	1
Hollow concrete brick masonry			1				1
Brick masonry in cement mortar			1				1
Single Panel Walling System							0
Interlocking bricks			1				1
Dhajji Dewari						1	1
Prefab-framed in-situ concrete							0

Table 6.4: Scoring card method (Shock Safe Nepal group 1).

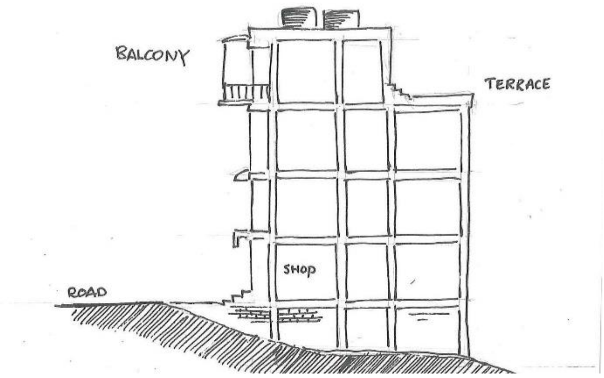


Figure 6.1: Typical RCC frame construction (Shock Safe Nepal group 1).

6.7 Conclusion

The short list is based on overall ranking, aspect ranking, scenario analysis, consistency within these rankings and comparison in pairs. Besides performances of building methods it should be taken into account the MCA is a tool that assists the decision maker, therefore it should serve as foundation for the short-list instead of adopt it as the absolute truth. The short-list of preferred building methods considered most suitable solution for the problem definition is:

- Reinforced Cement Concrete Frames
- Steel (with a remark on feasibility)
- Confined Masonry
- Stone Cement Masonry (with a remark on technical)

RCC frame and stone cement masonry are methods commonly known in Nepal, especially in mountainous areas, whereas steel structures and confined masonry are less common. Reinforced cement concrete frame scores highest in the MCA and is well known in ribbon developments. At the moment RCC frame is one of the most used methods for rebuilding ribbon developments (like Dunche), what makes it interesting to propose an 'updated' version of this method. RCC frame will be elaborated on in order to answer the research question and to propose a concept wise solution. The level of detailing will be schematic, since a detailed design does not fit in the scope and needs more research. The designs will be accompanied by an organisational and financial approach.

Summary of RCC frame building method

To give a brief summary of the RCC frame building method a SWOT is made containing all information gathered.

Strength:

- Functionality; maximum scores on building height and expendability
- Resources; material and experience is available

Weakness:

- Sustainability; materials are close to impossible to recycle or re-use, concrete factories have an environmental impact on large scale in the valley
- Redundancy when designed with few bays
- Difference in column length on slope

Opportunity:

- Technical; RCC has multiple solutions for improving the standard seismic performance,
- Improving architectural quality/ village identity

Threat:

- Feasibility; The price of cement/concrete is not constant in Nepal due to uncertain developments (for instance the oil crisis of 2015)
- Execution; expertise is not always present

7. Design

The design is divided into four sections: it starts by mentioning the technical challenges resulting into potential solutions to solve the mentioned challenges; these potential solutions are combined into a design proposal. With the design proposal the new organizational challenges are addressed.

7.1 Challenges

Many mountainous regions characterize large parts of Nepal. In these regions a scarcity of flat building sites, oblige people to build constructions on slopes. Due to the increasing population in the Kathmandu valley, migration and settlement is rapidly increasing in suburban areas along the highway corridors. Resulting in the linear settlements, earlier labelled 'ribbon developments'. These settlements are reached by hairpins roads, which are often of bad quality. For the residents of these settlements it is commercially favourable to place their house along the roadside (shops, restaurants, workplaces); roads which often traverse a hillside.

As determined in the previous chapters, it is known that buildings resting on sloping ground are more prone to earthquake damage than buildings resting on flat ground (Khadiranaikar, 2014). Such buildings have several structural vulnerabilities and challenges.

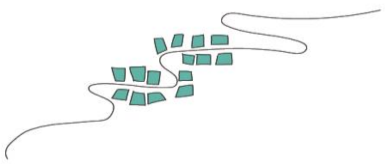


Figure 7.1. Ribbon development (own (Shock Safe Nepal group 1)

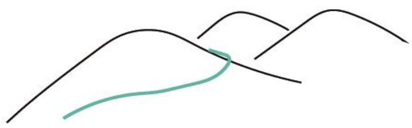


Figure 7.2. Hilly area (Shock Safe Nepal group 1)

Figure 7.3. Bad infrastructure illustration)

Building characteristics

The research focuses on a specific frequent occurring building typology; the commercial and residential RCC frame building. This typology is composed of two open bays for commercial functions combined with a narrow bay in the middle for the corridor leading to the apartments.

Typical dimensions of the storefronts are 3,0-3,5 m and for the door opening approximately 1,5m. Bays in the cross directions are 3-4 m. Building heights are on average 3-4 storeys. The typical plans (with shop and restaurant furniture drawn in) and elevation shown beneath are based on observations in the case study villages.

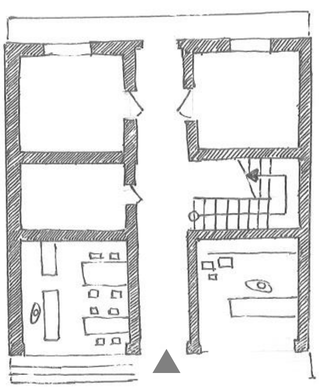


Figure 7.4: Typical plan of building (Shock Safe Nepal group 1).

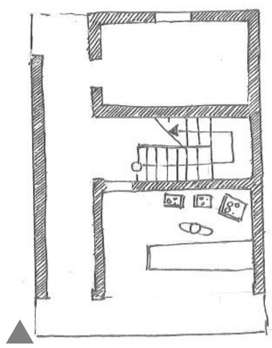


Figure 7.5: Alternative plan building (Shock Safe Nepal group 1).

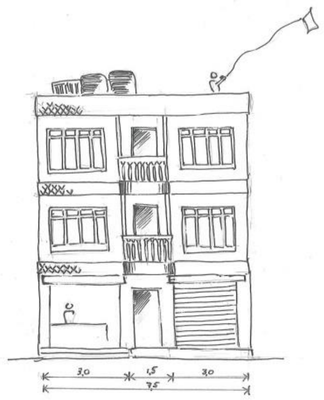


Figure 7.6: Typical elevation (Shock Safe Nepal group 1).

Social/ cultural factors

The buildings stand along lively roads, which are packed with shop stalls, parking, local traffic and also passing traffic. Oftentimes commercial functions are placed along the road in the form of open storefronts, restaurants or workplaces. These spaces extend towards the outdoors, leading to oversized and intensively used doorsteps for hanging out, work place or selling goods. In contrast to the more traditional building styles, the majority of roof of RCC-frame buildings is flat. Rooftops are intensively used for storage of water tanks, PV-cells, solar water heaters, hanging of laundry, playing with the kite or sitting in the sun.

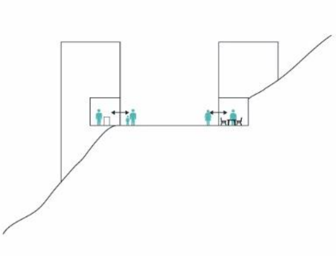


Figure 7.7. Commercial use ground floor (Safe Nepal group 1).

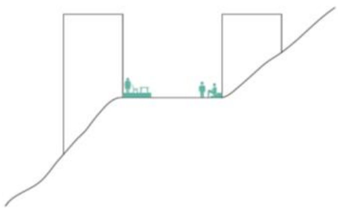


Figure 7.8. Extension to doorstep (Shock Safe Nepal group 1).

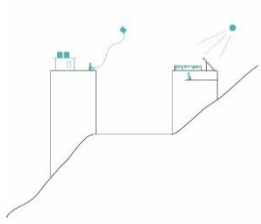


Figure 7.9. Roof top use (Shock (Shock Safe Nepal group 1).

Building factors

Construction sites are characterized by an informal building process, in which a head mason leads the construction team and house owners, family members, villagers help with the building process. The construction process is often incremental, building further whenever money is available or more rooms need to be rented. The frame structures are often extended, to leave opportunity for later expansion of the structure.

There is also little money for rebuilding, in relatively poor households.

Some additional limitations are building along a road. For increasing density of the traffic, it is hard to enlarge the road capacity. Furthermore, the buildings standing on downhill slope block the often-beautiful view on the valley beneath.

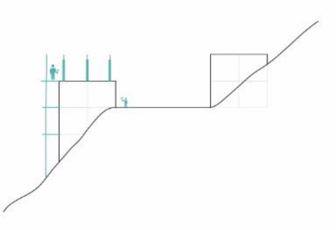


Figure 7.10: Informal building, little space (Safe Nepal group 1).

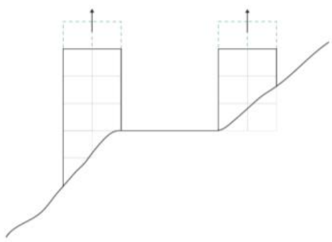


Figure 7.11: Vertical building expansion (Shock Safe Nepal group 1).

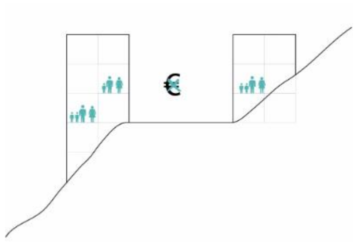


Figure 7.12: Small budget (Shock (Shock Safe Nepal group 1).

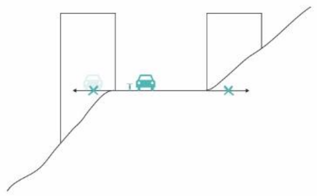


Figure 7.13: Limitations to expansion of road (Shock Safe Nepal group 1).

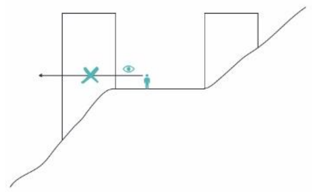


Figure 7.14: Blocking of view into valley (Shock Safe Nepal group 1).

Classification

For buildings on a slope, a classification is made by (Von Winterfeldt, 2000) into the categories up-hill slope and downhill slope. These building types demonstrate different challenges and characteristics.

Up-hill slope vs. downhill slope

Up-slope buildings are built on the slope rising above the street. The building foundation is set immediately on the ground or buildings are built into the ground (excavation). With the aim to minimize access and construction problems caused by the rising up land, main building levels are mostly seen above street level. The building is mostly relatively close to its foundation.

Down-slope buildings are built on the hillside that drops down below the street. With the aim to minimize access and construction problems caused by the dropping down land, the main building levels are mostly seen on street level, setting it relatively far from its foundation. For steep slopes, the building is therefore separated from the ground by substantial subfloor structures (irregular due to sloping ground). Down-slope buildings are generally of more storeys than uphill-slope, since downhill storeys sometimes need many stories beneath ground level to get to the road.

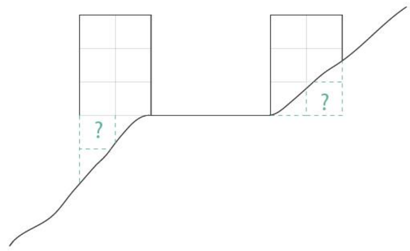


Figure 7.15: Building on a slope produces foundation challenges (Shock Safe Nepal group 1).

Stepback vs. stepback-setback

A classification is made between stepback buildings, having foundation on different levels, but one-roof height and stepback-setback buildings, in which also the roof height is setback along the hill. Studies indicate that stepback frame buildings are subjected to higher base shear and higher top storey displacement than step-back set back buildings (Dr. S. A. Halkude et al, 2013). Conclusion is that step back- set back buildings might be favorable on sloping ground (Khadiranaikar & Masali, 2014).

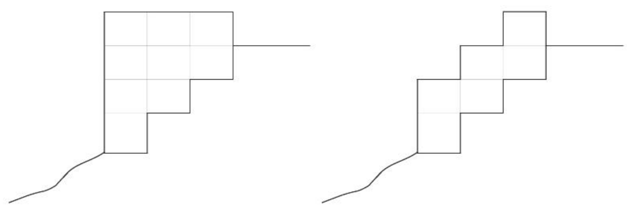


Figure 7.16: Stepback vs. Stepback-setback buildings (Shock Safe Nepal group 1).

Natural hazards

The mountainous areas of Nepal are challenged by multiple natural hazards or challenges, of which the most important are: earthquake loads, ground instability and monsoon.

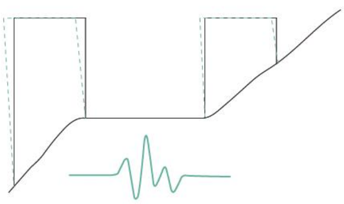


Figure 7.17 Seismic hazard (Shock Safe Nepal group 1).

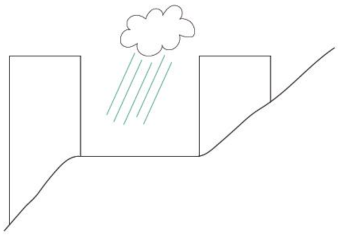


Figure 7.18: Monsoon hazard (Shock Safe Nepal group 1).

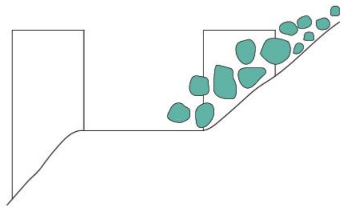


Figure 7.19: Boulder- and rockslide hazard (Shock Safe Nepal group 1).

Earthquake loads

The hilly areas of the Kathmandu valley are classified as a highly seismic region. The seismic response of a building depends on multiple building characteristics amongst which: building configuration, geometry, interaction of the foundation structural (subfloor system) systems with the superstructures, and so on (Liu). Earthquakes movements can be multidirectional. The movement can be decomposed into two principle directions:

- Shaking in down-slope direction
- Shaking in cross-slope direction

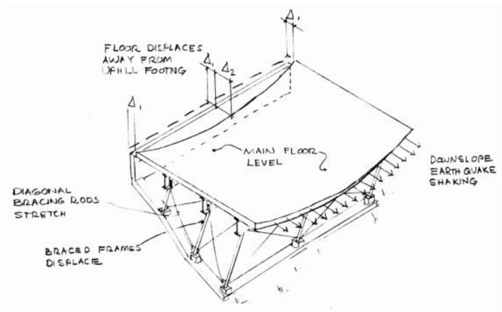


Figure 7.20: Braced frame – along hill shaking | Source PEER

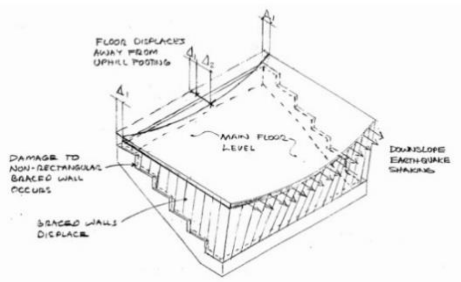


Figure 7.21: Braced wall – along hill shaking | Source PEER

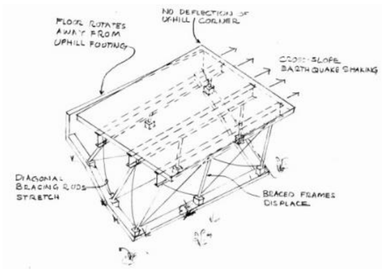


Figure 7.22. Braced w – along hill shaking | Source PEER

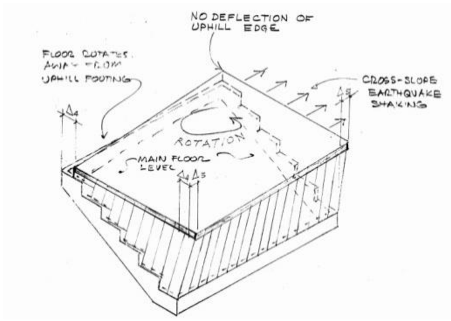


Figure 7.23: Braced wall – along hill shaking | Source PEER

Above pictures are representative for buildings on a slope in Los Angeles and are displayed here to illustrate the effect of the two main directions of earthquake motions to slope structures.

Monsoon

Nepal is characterized by a season of heavy rainfalls (monsoon) from *June to September/ mid-October.* The monsoon complicates the transport, impairing the unpaved roads. The heavy rainfall increases the risk of land- and rockslides.

- Mud- and landslides

Seismic movement can decrease the coherency of the ground of a sloped land. Earthquakes can provoke landslides at slopes that are unstable due to loose material. Risks are higher in rainy season, when the soil is wetter than in dry seasons (Brzev, 2011 2002).

- Boulder- and rockslides

Earthquakes can provoke rock falls, at slopes where fractured rocks and boulders lie in unstable configuration. Boulders can roll down slopes and crush or damage buildings. Risks are higher in rainy season, when the soil is wetter than in dry seasons (Bothara, 2002 2002).

Technical challenges

Buildings on slopes are generally irregular in configuration; they are unsymmetrical in both horizontal and vertical direction. This results in a centre of mass not coinciding with the centre of rigidity of building storeys and not aligning vertically for the different floors. These irregular configurations induce significant torsional response under cross-slope excitation and additional lateral load, making the buildings more susceptible to damage due to ground motion). The building tends to rotate because the lower subfloor element is more flexible than the higher subfloor element (Liu, 2011). Above-mentioned torsional irregularity in cross-slope direction is even higher for buildings on steep slopes/ vertical cuts, which have two levels of foundation. One at the road level, and one a few storeys beneath (Singh, 2012 2012.).

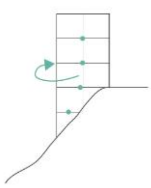


Figure 7.22: Cross-hill shaking causes torsion due to irregular building configuration (Shock Safe Nepal group 1).

- Unequal column heights / unequal height of subfloor system elements

Column foundations that stand on different levels within one story characterize buildings standing on a slope. Different foundation levels result in unequal column heights and a drastic deviation in stiffness between these columns. Both tall and short columns undergo the same amount of movement due to excitation. Under along-hill excitation the shorter and stiffer uphill column (element) attracts more earthquake forces; storey shear and bending moments *(Gade, 2011 2012)* than the longer flexible column (element) and is therefore more vulnerable to damage.

This effect is seen for buildings on piles, buildings on subfloor bracing system and buildings with sheathed timber subfloor walls.

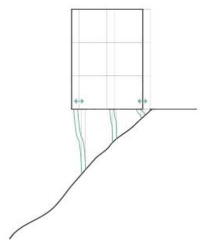


Figure 7.23: Unequal column length cause disproportionate stress to shortest column (Shock Safe Nepal group 1).

- Progressive collapse

The phenomenon can cause progressive collapse; the shortest and stiffest element will take the most forces. If it fails, the next shortest element will take the majority of forces and fail. This procedure might proceed until the structure has collapsed (Liu, 2011).

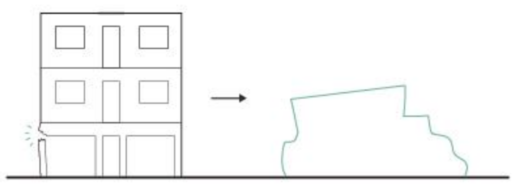


Figure 7.24 Potential lack of redundancy in frame structures (Shock Safe Nepal group 1).

- (Soft) story at road level

Structural analysis has indicated that for downhill-sloped buildings the storeys at road-level are most vulnerable to damage (Singh, 2012 2012). Many buildings have parking spaces, open storefronts, workplaces and restaurants at the roadside. These large open spaces create a soft story at this vulnerable point between hill and building.

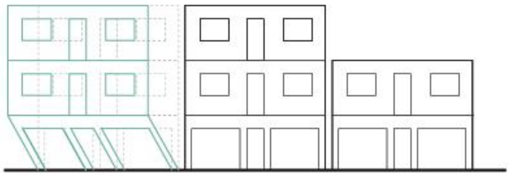


Figure 7.25: Soft story failure (Shock Safe Nepal group 1).

Soft storeys are much less rigid than the floors above, due to unreinforced openings or less infill walls at that storey. Since this story is less resistant to lateral loads it is subjected to a disproportionate amount of lateral drift. In result, the storey will be subjected to higher loads, while it is less capable of resisting these loads. This can cause severe structural damage or collapse (Chen, 2005). The collapse of this soft storey causes the above floors to pancake on top of it, crushing the elements beneath. Subfloor systems to provide foundation on the slope by means of piles without bracing, or with limited infill or shear walls can also be seen as soft stories.

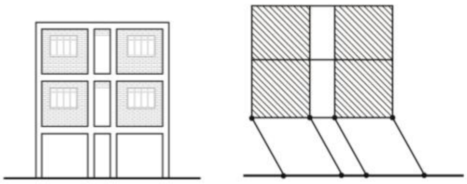


Figure 7.26: Soft story, no infill walls on ground floor for commercial functions (Shock Safe Nepal group 1).

Figure 7.27: Soft story failure at Chisapani (Shock Safe Nepal group 1).

- Pounding

Buildings are not provided with seismic gaps, and are therefore susceptible to pounding of adjacent buildings. There is a discussion if neighbouring buildings stabilize each other, creating positive effects for their stability.

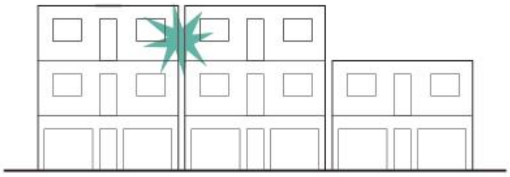


Figure 7.28: Pounding of adjacent buildings (Shock Safe Nepal group 1).

-Displacement of the floors

Displacement of floors and base shear is found to be higher for buildings standing on a slope than for buildings standing on a plain site (Kevyan Ramin 2013). Furthermore, top storey displacement and fundamental time period are seen to increase linearly with the height of the building (Birajdar, 2004).

-Overturning of buildings

The capacity to resistant overturning is lower than for buildings on a plain ground (Ji, 2012).

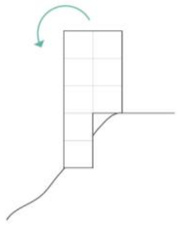


Figure 7.29: Risk of building overturning (Shock Safe Nepal group 1).

7.2 Potential solutions

For the challenges given in chapter 7.1 a number of solutions are given. A short description of the potential solutions is given

Stabilizing the slope

-Building measures

Both up-hill slope buildings as down-hill slope buildings can require specific structural systems to stabilize the slope and provide a foundation on the sloped site. Several slope-stabilizing measures are:

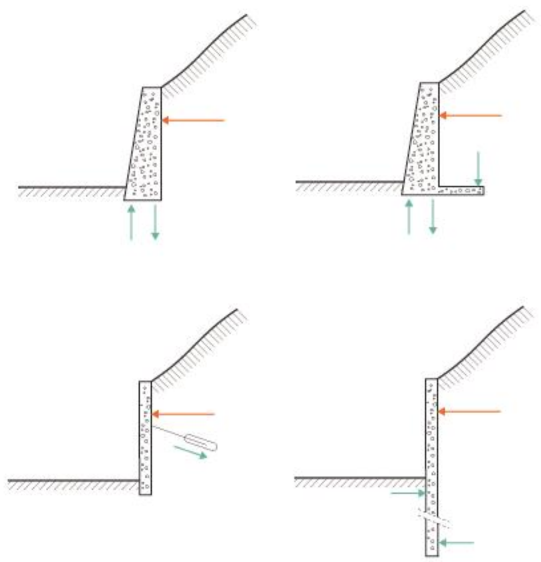


Figure 7.30: Methods of stabilizing the sloping ground. a) Retaining wall. b) Gravity wall. c) Anchored wall. d) Piling wall (Shock Safe Nepal group 1).

-Alteration of slope geometry

Slope risks can be lowered by alteration of the slope geometry in the form of excavation, digging out or terracing, lowering of raising land levels.

-Grouting, drainage schemes, green barriers

The roots of trees (for example bamboo) will penetrate into the soil and improve the stability of the ground.

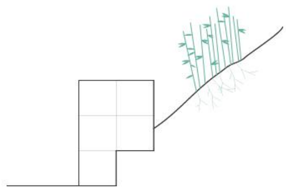


Figure 7.31: Green barrier (Shock Safe Nepal group 1).

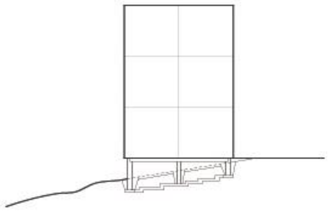
Foundation systems

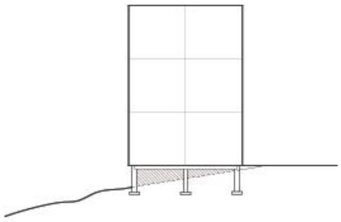
-Down-hill slope systems

Since the main building part is relatively further away from the foundation, down-hill buildings generally need additional provisions to meet the sloped surface. Within the range of potential subfloor systems, the suitable solution depends bearing walls or frame construction and the steepness of the slope). Foundations are characterized by different height of foundation elements; short elements on the uphill side and tall elements on the downhill side. Damage to subfloor systems can cause damage to upper parts of the buildings, or even collapse. Therefore, adequate strength is needed to withstand the earthquake forces and adequate rigidity to prevent excessive displacement (Von Winterfeldt, 2000 2000). The structure should be provided with redundancy to prevent progressive collapse if an element fails. Refer to appendix X to see an overview of subfloor systems, which were encountered in ribbon villages in the surroundings of the Kathmandu valley.

On the next page an overview is given of possible foundation systems. A differentiation is seen between systems for steep and moderate slopes.

Moderate slopes





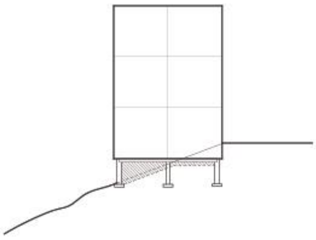
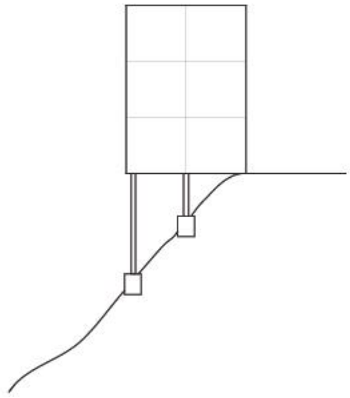


Figure 7.32: Stepped foundation (Shock Safe Nepal group 1).

Figure 7.33: Fill foundation (Shock Safe Nepal group 1).

Figure 7.34: Cut-and fill foundation (Shock Safe Nepal group 1).

Steep slopes



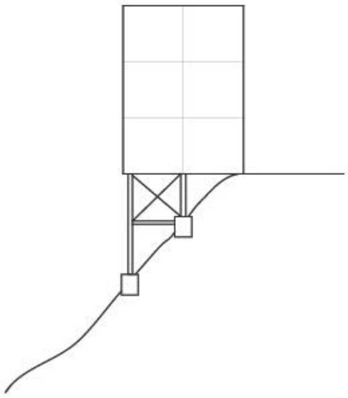
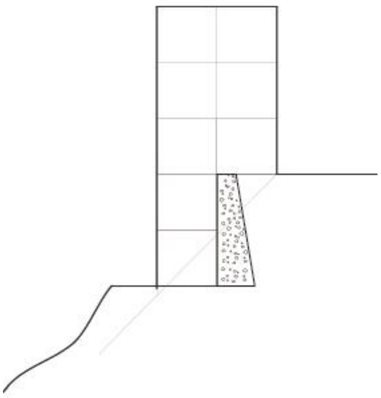
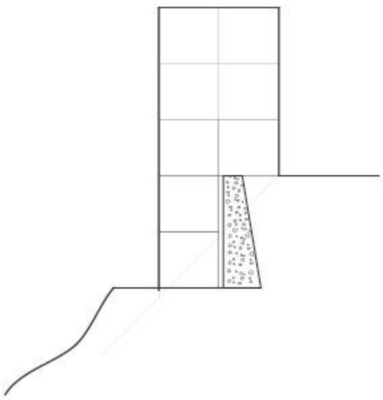


Figure 7.35: Pile structure (Shock Safe Nepal group 1).

Figure 7.36: Braced pile structure (Shock Safe Nepal group 1).





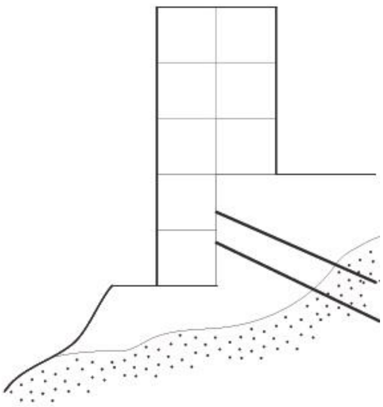
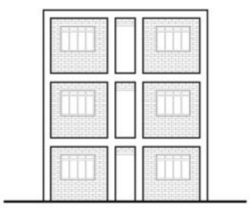
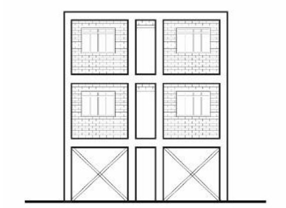


Figure 7.37: Retaining wall part of structure

Figure 7.38: Retaining wall lose from structure

Figure 7.39: Building anchored to stable ground (Shock Safe Nepal group 1).





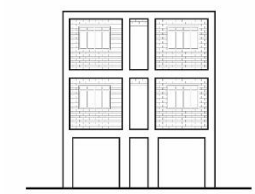


Figure3.40: Avoiding soft story; a) infill walls. b) bracing c) larger dimensions of ground floor columns (Shock Safe Nepal group 1).

Building configuration

Greater number of bays better performance
Increase of the number of bays improves behaviour under seismic excitation, due to a decrease of time period and displacement in hill slope buildings (Dr. S. A. Halkude, 2013). Overall seismic overturning resistant capacity decrease with the increase of unequal story numbers and the decrease of bay numbers (Ji, 2012)

-Unequal column length

The section of the shorter columns should be designed with greater resistance (for example with more reinforcement) to withstand these increased forces (Kumar, 2014 2014).

Torsion

Providing braced walls, shear walls and infill walls can resist torsion, which is generated by the irregular building configuration.

-Soft story

Soft storeys must be avoided by providing enough rigidity to the specific storey. For timber constructions this can be done by means of sturdy plywood diaphragms or diagonal bracing elements. For steel frames, bracing, shear walls and moment resisting connections can be applied. For moment resisting frames, connections and columns must be stronger than the beams, so hinges will form in the beams and not in the columns. Column failure must be avoided, since column failure forms a higher risk of total collapse. For RCC frame buildings shear walls, masonry infill walls and steel frame bracing can be applied

If soft storeys cannot be avoided special design provisions are needed. Several alternative solutions are:

- Increase of the sections at the soft story.

Designing the structural elements with much larger dimensions, for substantial higher loads; remaining the frame character.

- Provide composite columns

Strengthening the structural elements (columns or walls) of the soft story by providing composite elements. For example, composite concrete columns with encased H-beams (ArcelorMittal). The addition of steel elements provides the structure with more robustness, rotation capacity and ductility.

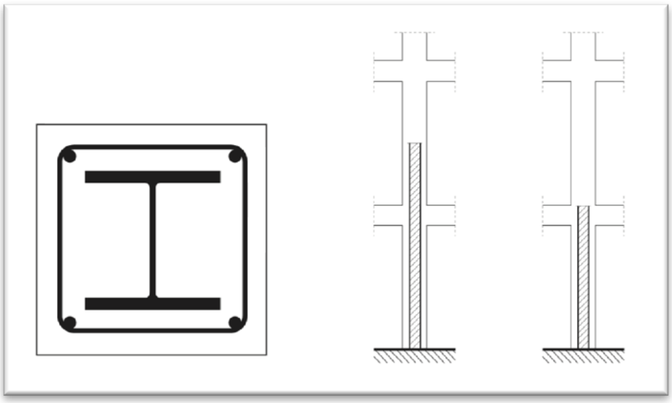


Figure 7.41: Left: Section of steel-concrete composite column, Right: Implementation in the ground floor, or up to half way the second floor of H-beam in concrete column (Arcelor Mittal).

-Stiff core

Designing a stiff elevator and staircase core to withstand the total base shear. In this way, the columns are only subjected to the gravitational load *{Guevara-Perez, 2012}*.

- Shear walls

The application of shear walls and (brick) infill walls are considered to decrease the lateral displacements of storeys and storey drifts by ground motions considerably in comparison to bare frame models (Umar, 2014 2014), (Hassan, 2013). However, base shear may increase demanding special attention in the design (Khadiranaikar, 2014). The bigger the arm of the shear or bracing walls, the larger the capacity to resist overturning forces.

7.3 Design proposal

Based on the prior analysis of the challenges of the chosen building type, and the research on possible solutions, a proposal is done for a building block made with RCC frame. It must be mentioned that this proposal is just an idea that needs verification and validation. The proposal addresses multiple issues, but also evokes some challenges.

The coupled block

The proposal is to couple 3 individual building blocks (prior of 7,5 m width) into apartment buildings. Building as such could lead to a reduction in construction costs, by decreasing the amount of structural elements needed (reducing the amount of columns and bordering walls), and ordering larger batches of raw materials.

In structural view, this proposal has multiple advantages. Multiple bays have a better earthquake performance (as concluded by multiple research, amongst which (Dr. S. A. Halkude, 2013)). Multiple bays also have a better redundancy, having more building elements to compensate for failure. For building blocks with larger dimensions than a narrow house, stabilizing elements can be placed further apart, creating a larger lever arm to withstand lateral forces in a more effective way (See fig 7.40) Combining several buildings might also provide the possibility to avoid soft-story; open storefronts can be alternated by fronts with more infill, which do not need commercial functions), providing the ground floor with enough 'body'.

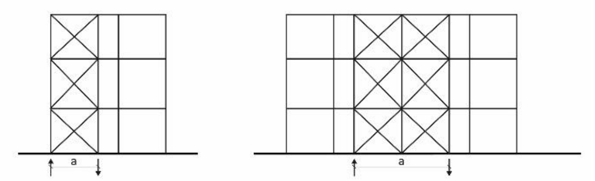


Figure 7.41: More bays provide the opportunity for a larger lever arm to withstand horizontal forces (Shock Safe Nepal group 1).

The dimensions are based on the structural restrictions/guidelines provided by the Building Codes, which state that the building length should not be more than 3 times the building width. Also limitations are placed on the bay length (not larger than 4,5 m).

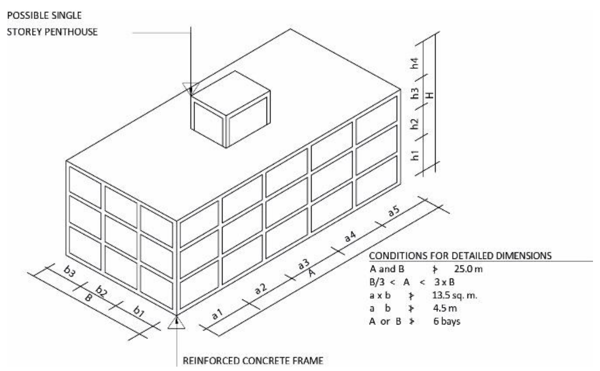
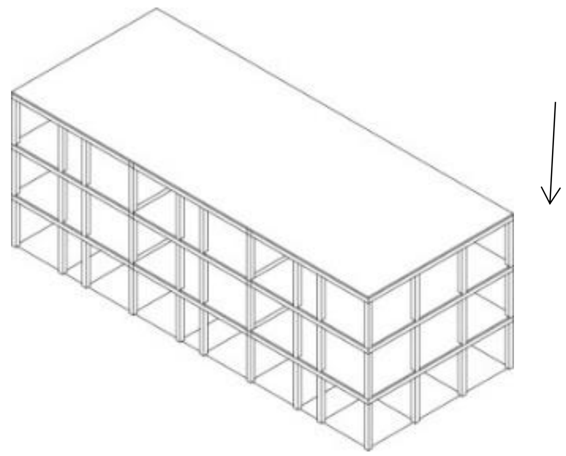


Figure 7.42: Structural configuration limitations | Source building code NBC 201:1994

This proposal poses some challenges:

- The division of construction costs
- The organization of construction and multiple future inhabitants/ owners
- The extendibility and informal construction possibilities
- The individual identity of the buildings (differentiation)



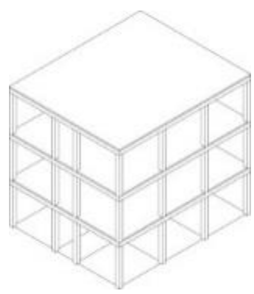


Figure 7.43: Moving from small-scale building to multiple bay building (Shock Safe Nepal group 1).

Hybrid solution

Measures are proposed to withstand the soft storey, and the additional forces induced by the placement on the hillside. A first proposal is a hybrid structure: to incorporate steel H-beams in the rectangular concrete columns, as also proposed by Arcelor Mittal. Composite columns are provided in the weaker building elements, which are for this building type the columns of the ground floor forming the soft story, and the 'short 'columns on the slope which are more vulnerable.

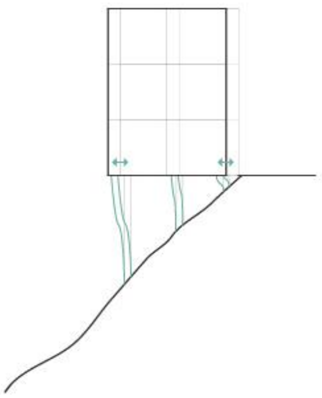


Figure 7.44: Unequal column length cause (Shock Safe Nepal group 1).

Figure 7.45: Soft story failure (Shock Safe Nepal group 1).

Disproportionate stress to shortest column

The steel H-columns have more stiffness in their main direction, therefore the steel sections could be partially rotated, to provide enough rigidity to withstand lateral forces in both directions.

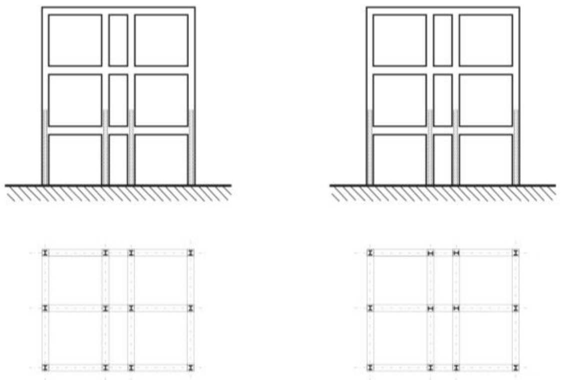


Figure 7.46: RCC frame with composite columns up to the first floor (Shock Safe Nepal group 1).

The hybrid solution is positively addressing the following problems:

- Strengthening the elements forming the soft story; while keeping the open storefronts or other commercial functions, parking spaces.
- Strengthening the 'short' columns on slopes, which are subjected to larger loads
- Increase of column capacity (whereas the addition of reinforcement rods has a maximum amount)
- Providing extra redundancy to the structure
- Providing extra ductility to the columns

Posing the following challenges:

- Increase of building costs due to additional steel H-columns
- Unknown practice

An alternative to the composite columns is to place shear walls at strategic places in the building. This decreases the flexibility of shop openings.

Shear walls

The application of shear walls increases the lateral load resisting capacity of RCC frame buildings significantly (Sud, Shekhawat, & Dhiman, 2014). Shear walls are ideally placed symetrically. Shear walls in the façade are favored above the elevator core; placing stabilizing elements in the perimeter provides a larger lever arm to withstand lateral loads. Sud, Shekhawat & Dhiman (2014) claim on the basis of structural analysis that placing shear walls at midwalls has the best overall earthquake performance. This placement of shear walls has the highest symmetry. In case a shear wall is not possible in the façade facing the street due to commercial functions, 3 shear walls are placed and the side walls should compensate (by means of extra dimensions) for the lacking wall at the storefront.
The proposition with composite allows for more flexibility on the ground floor. A feasibility study should be done in order to determine which option is preferred.

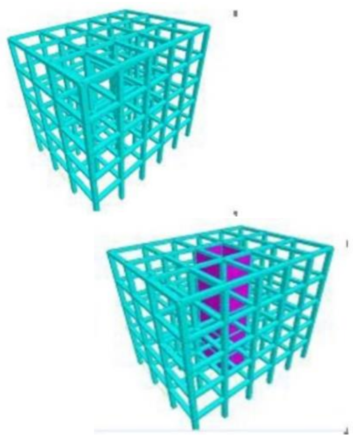


Figure 7.48: Frame 1) No shear walls, Frame 2) Shear walls at the core

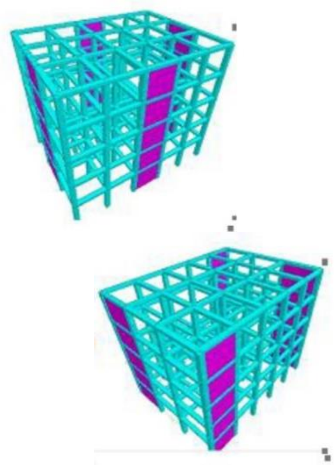


Figure 7.49: Frame 3) Shear walls at mid walls, Frame 4)Shear walls at corners |Source: (Sud, Shekhawat, & Dhiman, 2014).

RCC-frame exterior

The RCC-frame buildings are characterized by brightly coloured 'candy cane' architecture. A proposal for the RC-frame exterior is done, which is more in harmony with original architecture, but which does not deny the inherent RCC-frame structure of the building. The proposal also tends to address the following problems; RCC-frame buildings have cantilevers with floating columns. And apartment blocks threaten to diminish the identity and feeling of owning a building of the single house-owner.

The idea is to restore the balconies with poles reaching to the ground, avoiding cantilever and creating a shaded spatial enclosure on the extended living space on the doorstep. The alternating balconies cut up the larger apartment volume, contributing to the individual identity of the combined housing blocks.

Aspects original architecture:

- Pitched roofs
- Earthen/natural colours for walls, coloured (for example blue) or timber doors/ window frames
- Supported balcony in the form of open colonnade
- Open colonnade instead of corrugated steel shopfront

Figure 7.50: Apartment block proposal with alternating balconies (Shock Safe Nepal group 1).

Pitched roofs are more in harmony with the original architecture. Furthermore, they provide lighter roofs and with the angle, a better rainwater drainage. However, inhabitants intensively use the flat roof terraces. Therefore a 'cut-out' is proposed in the roof, referencing to the Model Village of Rabindra Puri. This cut-out provides the open space on the roof for kiting, sitting in the sun and drying the laundry.

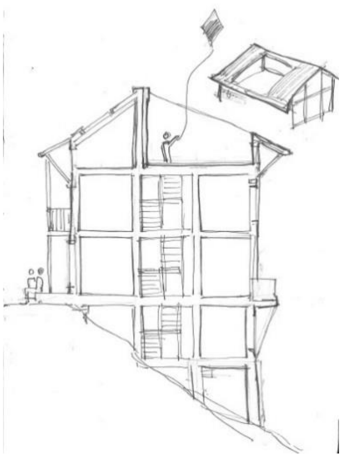


Fig 7.51: Sketch of roof terrace use (Shock Safe Nepal group 1).

A cluster of apartment blocks is visualized on the sketch below. The apartment blocks have limited length, following the structural principles of the building code. Buildings could be alternated with small squares, which provide meeting points for the community, sparing some space on the road. Furthermore, these squares provide a see-through towards the view on the valley; enhancing the spatial experience and the sense of landscape and nature.

Figure 7.52: Cluster of apartment blocks (Shock Safe Nepal group 1).

Positively addressing the following problems:

- Creating a lighter roof
- Avoiding cantilever of balconies
- Creating a shaded outdoor area
- By densifying certain buildings, opportunity is made for public space in the form of squares along the roadside. Offering views into the valley and space for community bonding (games, gathering etc)

7.4 Organisational challenges

With the proposal to combine three individual building blocks into a coupled block organisational challenges might arise. In Nepal, families are often the owner of a piece of land where they build their house, with the ownership of land and house passing from father to son. In the case where building blocks are coupled there are some organisational challenges and benefits.

Ownership

In coupled block proposal an issue in house ownership might arise. Full ownership of the coupled block might be too costly for one family, however shared ownership creates challenges in maintenance and future expansion. In some cases an external investor might be needed to realise the construction. The organisational aspects in which a coupled block building can be realised are formal (official home owners association) and informal (community trust fund). More research is needed to prove if this method could work in Nepal.

Repetition of construction

The proposal of combining three buildings into a coupled block could work in the entire region. The existing RCC frame houses are already largely standardized regarding grid and column sizes, more or less a copy of each other. The main focus point in the repetition are the changing slope conditions, since the area has a mountainous character each building site will always be unique due to the different slope conditions. Repetition is possible in the preparation before construction: transportation of building materials and training of labour. With an experienced labour force and repetition of the construction the quality will improve while shortening the construction time.

Stakeholders

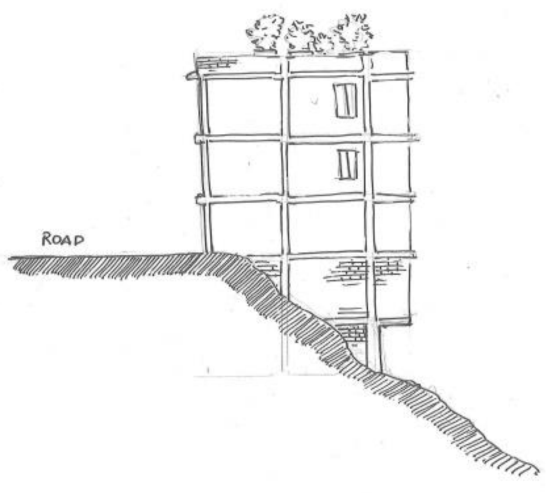
To implement the proposal of a coupled block the plan should be issued within the DUDBC, the highest construction authority. On paper the rules of construction are strict and not constructing by the rules could result in cancelling of constructing permits. If the plan can be implemented from a higher level and included into the Nepalese building code the plan might be successful. The construction of larger building blocks also

increases the need for construction knowledge; therefore knowledge institutes should be included in the process. According to the design the building should be able to withstand a serious earthquake but a good design is worth nothing when construction is not properly executed.

Life cycle

Construction of houses in Nepal often happens in phases; a design is made of a building with four storeys, the construction starts with only the first floor, when over time the resources are available the construction of the next floor will be initiated. When three houses are coupled the expansion should be synchronised, the possibility of building in phases should also be included when looking for a potential investor.

When combining three building blocks into coupled block maintenance does not stop at one section of the house. All the parties should be aware of potential maintenance in structural parts of the building. These parts affect the entire block of building and are therefore a shared responsibility. All the inhabitants in the coupled building have a shared responsibility over the building; this should prevent inhabitants from construction informal expansions, which could diminish the structural strength of the building.



Cost – Benefits

Financial analysis should point out whether construction costs are feasible for average house owners in Dhunche. In order to perform this analysis actual data on construction costs are needed, as described in the limitations of report 1 actual data is missing due to the unstable market and project scope. Also the government has not given clarity on the exact amounts people will receive or able to loan. Since Dhunche is located outside of the Kathmandu Valley the promised loan amount can be up to 1,5 million Rupee (which is more or less equal to €12,500), as described in rapport one.

For people to construct their house the financial analysis should have a positive outcome, so A<B. In case only the costs for the standard construction costs of RCC Frame are feasible for the house owners (C1+C3<B, but A>B), we could propose a subsidizing plan to make it feasible. Due to the subsidy plan house owners should be able to use steel and additional concrete for steel-concrete composite columns and shear walls.

This subsidy plan is only feasible for Nepal if C<D. Even with a negative balance there could be reason to still adopt the subsidy plan. Somewhat comparable are the Dutch water defence systems (Deltawerken), which had a negative balance, however were adopted anyways since the loss of life and local economy were undesirable (also due to social pressure). A reference for such a subsidy plan is the Japanese program after the 1995 Great Hansin earthquake that struck Kobe, in which they proposed subsidies (mainly) for inspection and retrofitting of existing housing to make them earthquake resistant {Suganuma, 2006}. Such a subsidy and tax breaks encourage inhabitants to make the necessary changes to make their house earthquake safe.

Cost	Budget
C1) Construction cost 'standard' RCC frame **C2)** Construction cost additional measures (hybrid) **C3)** 2% interest rate on government loan ---------- € A (=C1+C2+C3)	**B1)** Equity **B2)** €1,700 (government gift 'up to' amount) **B3)** €12,500 (government loan 'up to' amount) --------- € B (=B1+B2+B3)

Table 7.1: Schematic Financial Analysis

Cost	Benefit
• Subsidize costs hybrid techniques: import, transport and labour training of steel -------- € C	• Decrease in possible loss in case of earthquake (damage on build environment and infrastructure, loss of life, negative impact on economy) • Economical input due to 'new' sector; creating jobs --------- € D

Table 7.2: Schematic cost benefit analysis.

8. Discussion

The conducted research contains a general research setup and three main steps; Solution Space, Multi Criteria Analysis, and conceptual design. Within each step there are a larger number of smaller steps leading to the answering of the proposed research question. During the execution of the research a number of limitations and setbacks were encountered, in this chapter we critically look back on the work that has been done. The main components of this discussion will be scope definition, the requirements solution space, the multiple criteria analysis and the conceptual design.

The scope definition

During the initiation of this project many vision, goals and ideas were discussed, combined, rejected and accepted. During the course of the preparations a very clear understanding and vision was formed regarding Shock Safe Nepal as a knowledge platform. During the translation of the scope to practical tasks some differences in expectations emerged which needed to be settled. One extreme of the discussion was focusing only on the creation of a solid base which would serve as a tool for following groups while on the other end of the discussion the focus was put on delivering a full design on a preferred building method. The final conclusion was the creation of two reports: one being the base of Shock Safe Nepal and one being a showcase of more elaborated research on a specific topic. In the end we discovered that doing both was a larger task than we had expected, resulting in much time being spent on the development of the reports, with more limitations than we had wanted.

Limitations of the Solution Space and building methods

The Requirements Solution Space is a tool which can eliminate solutions based on the requirements set by the owner, rules and regulations, user demands and other binding criteria. The exclusion by Solution Space is generally based on crisp requirements and needs, and focuses more on the hard boundaries. However it creates difficulties when bordering with subjective and/or qualitative

values, in this research this is an issue we have encountered several times.

- *Lack of quantitative data* regarding building methods made it difficult to compare the performance of a building method with the harder and crisper requirement. A manner to solve this issue without resulting in very complex theories e.g. fuzzy sets was by creating a semi-quantitative scoring system. This allowed for the valuation of building methods in classes representing a quantitative or qualitative performance range.
- *Subjectivity of classifying building methods* was a limitation that arose with the creation of the semi-quantitative scoring system. Setting the initial scale was a difficult job due to interpretation errors and the scoring according to this scoring system sometimes proved even more difficult due to interdependencies and combinations of several elements within one score. Therefore the outcomes of the Solution Space and MCA are very dependent on the awarded scores.
- *The validation of minimum requirement values* was an important step in the process. The data used for the defining of these minimum values was obtained from several types of sources. Some more reliable than others. Much of the data was verified by means of a questionnaire and the plan was to use a different type of questionnaire to check if the chosen minimum values corresponded with the reality. However an attempt to validate data by means of a questionnaire back-fired due to difficulty of the questionnaire (which was already adapted so it would not be too difficult), resulting in flawed answers. The lack of validated minimum values was accepted as a limitation and the second attempt was never finalized.

Limitations of MCA

The Multi Criteria Analysis is a ranking tool which is based on the semi quantitative scores corresponding with the building methods. It determines the ranking of a number of variants by using assigned scores and assigned weights per score. The method has some limitations and dependencies however the tool is intended to assist the decision maker instead of giving an absolute answer.

- *The dependency on the assigned scores* can have a serious impact on the reliability of the outcomes. When the grading person is biased towards a certain building method, this person can influence the assigned scores which may have consequences for the final ranking position. The sensitivity analysis has shown that the final outcome can be significantly different if an aspect that has received much weighting scores a point more or less. To prevent this; the grading have been cross checked and rechecked after some time period to see if views were still the same and there was still an agreement on the scores. When a final decision was taken regarding the scores, the motivations were registered for future reference.
- *Scaling of qualitative values* is quite subjective; therefore generating scales with comparable ratios for each requirement is difficult.
- *The weights of the aspects* are determined by the Shock Safe Nepal team members after all the experiences in Nepal, these views are validated with Nepali architects and corrected accordingly. However the assigning of the sub-weights for some requirements are based on interviews only or solely on the view of the Shock Safe Nepal team, affecting the final outcome. As with the validation of the minimum requirement values, many difficulties were experienced in the validation of the main weights. Eventually this validation worked for the main weights but also gave the understanding that it would be too difficult to accomplish a validation for all sub-aspects in the short time period that was remaining. This lack of validation in the determination of the sub-weights has been accepted as a limitation.

Limitations of the conceptual design

The conceptual design is intended as a showcase of the possibilities when more elaborated research is done on the topic. It shows the possibilities of a solution space and MCA approach in the identification of possible and preferred building methods and it shows the room for analysis on organisational and technical aspects.

- *The design mainly followed from findings* however some elements in the design were more an architectural choice than based on direct findings. This limitation was accepted due to the fact the design serves more as a showcase than in fact an actual proposal.
- *The validation of designs* was also not performed for the same reasons as the design principles and this limitation was also accepted for the same reasons.

Force majeure limitation

The cause of some of the limitations was the blockade making travel extremely difficult and leading to a lack of information and validation possibilities. This limitation was partially solved by reducing the field study radius to 50 km from the residence of the students, only visiting villages that were within cycling distance. This enabled us to obtain data by combining information found in ribbon developments that were not built on a slope and non-ribbon developments that were built on a slope. However some pieces of information could not be obtained and the validation process was partially hampered.

9. Conclusion

In the conclusions an effort will be made to answer the research question with the information from all previous chapters. The proposed research question is: *"What are the preferred post-earthquake reconstruction solutions, which are distilled from the solution space bound by social-cultural, financially feasible, technical, resource, functional and sustainable aspects, for Ribbon Development in Dhunche which can be representative for all Ribbon Developed Settlements in post-earthquake Nepal?"*

In the process of answering this research question much information has been uncovered by means of interviews, meetings, questionnaires, observations and literature. This information was used to determine the solutions space requirements and criteria, the minimum values for these requirements and the weights for the Multi Criteria Analysis (MCA). To determine the preferred solution, first all possible and realistic solutions needed to be identified. This was done by grading the criteria of the building methods from report one and matching these grades to the minimum requirement values. The minimum requirement values span the solution space of minimum criteria the building methods need to meet. This resulted in the exclusion of the following building methods with respective reasoning:

- Low strength stone masonry, due to insufficient seismic performance, lacking possibilities regarding expandability and workspace;
- Low strength brick masonry, due to insufficient seismic performance, lacking possibilities regarding expandability and workspace;
- Adobe, due to insufficient seismic performance, amount of required maintenance, limitations regarding storeys, vertical expansion and workspace;
- Rammed earth, due to insufficient seismic performance, amount of required
- maintenance, limitations regarding storeys, vertical expansion and workspace;
- Bamboo, due to the short lifespan and extensive amounts of maintenance needed;
- Earthbags, due to the proven seismic performance, the possibilities regarding storeys, vertical expansion and workspace.

The remaining building methods are considered to be acceptable for rebuilding in Nepal. However some were accepted to be allocated within the solution space with a remark due to 'failure' on one of the aspects. This failure however is considered to be 'fixable'. After all possible and realistic solutions were identified, the question remained which would be the most fitting solutions for the chosen case village. For this a MCA was executed.

The MCA contained criteria based on the solution space aspects with weights based on obtained viewpoints validated by Nepali architectural students. To incorporate a degree of reality in the outcome of the MCA four scenario are designed to represent several realistic possible futures. The first scenario is the "current situation" where subsidy is still uncertain and there are limitations on material availability. The second scenario where "no subsidy" would be appointed by the government for the rebuilding of houses resulting in limited resources. The third scenario where "subsidy" would be appointed by the government and on top of this some additional external funding is possible e.g. loans, resulting in sufficient financial resources. And the fourth scenario where "material availability" would not be an issue taking away import related restraints. The MCA resulted in the top five ranking of building methods per scenario as seen in table 8.1.

	Current situation	**No subsidy**	**Subsidy**	**Material available**
1.	RCC frames	Stone cement masonry	RCC frames	RCC frames
2.	Stone cement masonry	RCC frames	Steel	Confined masonry
3.	Confined masonry	Confined masonry	Stone cement masonry	Steel
4.	Steel	Brick cement masonry	Confined masonry	Timber
5.	In-situ shear walls	Hollow concrete bricks	In-situ shear walls	Light weight steel profiles

Table 8.1: top five ranking

Based on these outcomes and the obtained knowledge regarding construction in Nepal a shortlist of preferred building methods can be formulated that can be considered the most suitable solution, providing an answer to the research question. The following short list is proposed as the preferred post-earthquake reconstruction solutions for Ribbon Development Dhunche which can be representative for all Ribbon Developed Settlements in post-earthquake Nepal.

- Reinforced Cement Concrete frames
- Steel (with a remark on feasibility)
- Confined masonry
- Stone cement masonry (with a remark on technical aspect)

To showcase the possibilities of a more extensive research, one of the building methods out of the MCA short-list was chosen for further elaboration. Before the creation of a conceptual design some characteristics and challenges of the case village and function were mentioned to aid in the designing process. Buildings are preferably not built on sloping grounds in seismic areas. However, due to increasing population and a scarcity of flat buildings sites building on slopes might become unavoidable. Therefore first the problems and characteristics of the case study context are mapped which should be taken into account in the proposed solution.

Characteristics and challenges

- Social cultural characteristics: Commercial use of ground floor (shops, restaurants, workplaces), extension of doorstep as living area, intensive use of rooftop.
- Building and economical: Extra foundation measures needed for building on a slope, construction practice characterized by informal and incremental building, limited financial means.
- Natural hazards: Earthquake loads, monsoons, and land/ rockslides.
- Structural challenges: Irregular building configuration inducing torsion, unequal column length, commercial functions ground floor increasing the risk of soft storey collapse, pounding
- Challenges of building along a road: block of view into the valley, limited possibility of road expansion, elongated social scene

Design proposal

Out of the overview which is made of partial solutions to solve the before mentioned characteristics and challenges, an integral design proposal is made. The design proposal is an coupled apartment block. By coupling the narrow apartment, many structural challenges are addressed such as; pounding, creating a larger lever arm, creating more opportunity to prevent soft-story. Also construction costs can be saved by eliminating the double columns and boundary walls. Where this proposal addresses many structural challenges, it also poses some organization and cultural challenges. How do people feel about living in an apartment? How to safeguard the individual identity of the house? Who pays for what?

The soft storey can be addressed by placing shear-walls somewhere in the building. A hybrid solution is proposed, applying steel-concrete composite columns in the first storey columns which are subjected to lateral displacement. An alternative are the application of shear walls, to increase the resistance to torsion. Further study is necessary to determine whether these measures are economically feasible.

For the exterior of the building a proposal is done to provide an alternative from the brightly coloured concrete architecture towards an aesthetic which is more in harmony with traditional aesthetics. Instead of cantilevers and floating columns, balconies are supported by poles which reach to the ground, creating a shaded area on the extended doorstep. By alternating the balconies, the larger building mass can be cut up, creating some individual identity for the building blocks. Light pitched roof, conflicts with the intensive use of roof terraces; therefore a cut-out is proposed to provide outdoor space on the roof.

10. Recommendations

This chapter will elaborate on the recommendations for further work and research. These recommendations can be divided into seven items:

Validation of proposed design

The concept design should be validated by Nepali experts (engineers, students, professors) and by home owners in the intended case village. Validation will provide input for further architectural and functional designing before further and more complex analysis are made.

Variant development

The results of this research have shown that there are more solutions possible for the selected case village. An elaboration of two or more variants can lead to interesting comparisons between different building methods in which more detailed information can be used in the decision of preferred building method.

Architectural design

The concept design should be developed towards final designs. What variations can be made in the layout of the building? Should blocks just be joined or should they also share entrances and staircases? What is the best roof solution since there are conflicts in architectural, climatological (pitched roof) and functional aspects (flat roof). More studies should be done on usage of houses and characteristic floor plans. How can facades of RCC frame buildings be adapted to more cultural and historical architecture?

Structural analysis of proposed design

The concept design does not give answer on the amount and level of additional measures. A structural analysis should point out to which extend shear walls and steel-concrete composite columns should be applied for the seismic activity of Nepal. Could one of the two measures be sufficient? If so, a feasibility study should point out which measure is the most feasible regarding material (availability, transport) and cost. What is the overall seismic performance of a usual RCC frame compared to an upgraded hybrid RCC?

Feasibility study on proposed design

If the hybrid RCC frame is to be implemented on large scale a feasibility study should point out whether sufficient resources (material and capital) are present. Large scale construction demands availability of material. A financial analysis should give clarity on feasibility for the home owner. A Cost Benefit Analysis should give an overview of the economic consequences and provide ground for possible governmental subsidies (on construction material for instance).

Uphill vs downhill

The proposed concept design addresses mainly the more challenging problems of the downhill located houses. Further research and design should point out whether the proposed downhill design is also the most suitable solution for uphill located houses. Is the downhill concept design over dimensioned when used for uphill locations?

Implementation plan/Execution of construction

Execution of construction has problems concerning lacking quality and knowledge. Obvious mistakes are made: rebar to close to the concrete surface, too large aggregates, plastics and corrugated sheets poured in concrete etc. How can a proper execution be guaranteed; training, quality management, site management etc.? Since expandability (by adding a floor) is common development in RCC frame buildings it is important to guide this process in order to avoid unsafe structures. Potential expansion should be taken into account upfront, in order to properly dimension the structural elements. What construction and organisational methods can provide flexibility in extending?

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