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Building in Nepal: Support in constructing new anti-seismic houses after the earthquakes of 2015

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TREBALL FINAL DE GRAU

ABSTRACT

Title: Building in Nepal: Support in constructing new anti-seismic houses after the earthquakes of 2015

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Nepal is one of the 48 countries considered by the United Nations as developing countries. Its problem comes mainly because of three factors: its geographical situation, caused by being hidden between the great Asian giants such as China and India; the political instability of the last decades, which has caused the country to not be able to achieve a healthy national economy, and lastly, the constant exposure to natural disasters.

Apart from the annual rainy season (Monzó) that causes floods and damages year after year, the location of the country on the subduction zone of the Indian plate under the Eurasian plate causes high seismic hazard to the country. On 2015, because of this reality, two earthquakes of magnitude 7.8 and 8.1 shook Nepal on 25th of April and 12th May. Due to this fact, 80% of the buildings were damaged, from moderate damages until the total collapse.

It was at that time when was created the habitat improvement program AWASUKA, from the Base-A Association, which has been for two years in Bhimphedi doing this program, and which I have supported with the contribution of this study and a 25-day cooperation stay at the site.

The following document is divided into two parts. The first, refers to the theoretical part of the thesis; It consists on a search of the reality of Nepal and its architecture, and later on the seismicity and how the buildings in that country can be resistant. Even though, the second part of the work is practical, directly for the Association as support for the program. The task has been to execute a simple geotechnical study of a new construction site (in Suping ward, Bhimphedi) and the design of a seismic-resistant foundation system for the new houses to be built there.

In addition, this thesis details the tasks carried out during the cooperative stay and which have helped to make possible the reality of this project.

RESUM

Títol: Construir al Nepal: Suport en la construcció de noves cases anti-sísmiques després dels terratrèmols de 2015

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El Nepal és un dels 48 països considerats per les Nacions Unides com a països en vies de desenvolupament. La seva problemàtica ve deguda principalment a tres factors: la seva situació geogràfica, que causa que quedi **amagat** entre els grans gegants asiàtics com són la Xina i la Índia; la inestabilitat política de les últimes dècades, que ha causat que el país no fos capaç d'assolir una economia sana, i per últim, la exposició constant als desastres naturals.

Apart de l'època de pluges anual (Monzó) que causa riuades i desperfectes any rere any, la ubicació del país sobre la zona de subducció de placa índica sota la placa eurasiàtica provoca que el país esdevingui de perillositat sísmica elevada. Al 2015, en conseqüència d'aquesta realitat, dos terratrèmols de magnituds 7,8 i 8,1 sacsejaren Nepal els dies 25 d'abril i 12 de maig; degut a aquest fet, el 80% de les construccions es van veure perjudicades, des de manera moderada fins al col·lapse total,.

Va ser en aquell moment quan va aparèixer el programa de millora de l'hàbitat "AWASUKA", de l'associació Base-A, que porta dos anys a la població de Bhimphedi duent a terme aquest programa, al qual he donat suport amb l'aportació d'aquest estudi i una estada de cooperació de 25 dies a l'emplaçament.

El següent document està dividit en dues parts. La primera, fa referència a la part teòrica de la tesi; consta d'una recerca sobre la realitat del Nepal i la seva arquitectura, i posteriorment sobre la sismicitat i com poden ser resistents a ella els edificis en aquell país. Per altra banda, la segona part del treball és de caire pràctic, directament encarregada per l'Associació com a suport al programa. La tasca ha estat dur a terme un estudi geotècnic simple sobre un nou terreny de construcció (al barri de Suping, Bhimphedi) i el disseny d'un sistema de fonamentació sismo-resistent per les noves cases a construir allà.

A més a més, en aquest treball es detallen les tasques dutes a terme durant l'estada de cooperació i que han ajudat a fer possible la realitat d'aquest projecte.

ACKNOWLEDGEMENTS

To my tutor Xavier, for all his time, patience, encouragement and his belief on the project.

To the responsible of geotechnical laboratory, Rodrigo, for his immense help, patience, and time during the soil testing. And for allow me to use these installations for my project.

To all AWASUKA team, for this opportunity and their confidence deposed on me.

To all Bhimphedi volunteers, for their help and for making the stay such special.

To my family and friends, for their support, their ideas and their belief on me.

SUMMARY

1. PREFACE

1.1 ORIGIN AND PROJECT'S MOTIVATION

The main purpose of this project is to apply the knowledge acquired during the university degree *Enginyeria Tècnica d'Obres Públiques*, cursed at *Escola Tècnica Superior de Camins, Canals i Ports de Barcelona* (ETSCCPB) in a real project for a developing country and, thanks to it, officially finish the mentioned degree.

Even usually thesis or projects done by students of this degree are hypothetical small projects or thesis about a very specific subject with a non-special interest, the style of this thesis plus theoretical project changes this inertia. The motivation on this dissertation is to bring all the technical background learnt during the degree into places in the world with a real problem, and the necessity of people luckier than them that have been able to study how to solve it. And, once the necessity is detected, cooperate local people with foreigners to find a solution and learn from each other. All this motivation has been the promoter on getting contact with a NGO, visiting Nepal and have studied the best solution for them.

In addition, this technical degree pretends to train or educate students avid of knowledge on the complex science of infrastructure building. It includes a wide knowledge about all types of construction (from city buildings to village roads passing through all infrastructures and structures) in their project or design phase and, punctually in last years, also teaches students about construction phase. But, taking a global perspective, there is big lack of information about the possible synergies with other disciplines, technical or not. Thanks to AWASUKA program (which will be explained later), it has been possible to cooperate architects, engineers, workers for a same project, since the design phase to the real execution.

Also, an academic motivation for this project has been the introduction to seismicity and the Earthquake engineering, completely unknown for Spanish students of construction trade, since Spain is not considered an active seismic area and, consequently, is not a priority on ungraduated study programs.

2. INTRODUCTION

2.1 PROJECT'S OBJECTIVES

The project has not a unified or unique object but, instead, it can be clearly differenced two big blocks with different objectives: a theoretical fragment about Nepal and seismicity, and a practical case consisting in the elaboration of a geotechnical study and a foundation system design. Both sections apparently can seem way differenced but they're both closely dependent.

The objectives in the first block is to study and research information about the reality and the complexity of Nepal's construction. This includes an exhaustive research of their culture, traditional architecture and, one of most complex issues to solve in this dissertation, how affects being an active seismic area to construction.

Once done the previous study, the objectives of the practical second block is to put in practice knowledge learnt by the research in solving a foundation's project. This project will include, previous to design itself, a geotechnical study of the soil of the emplacements, and in consequence, an exhaustive soil testing on laboratories and in site, by travelling to the emplacement itself.

Additionally, it is necessary to make clear that the global objective as a whole is to help with this dissertation to AWASUKA program in designing their anti-seismic houses and socially and cooperatively help the Nepali village of Bhimphedi.

2.2 PROJECT'S REACH

In this section is going to be detailed the different limitations that have suffered or delimitated the project from its fist beginning:

- It is known that there are already easy and better solutions for dealing with the necessities asked, but because of the project's reality and the area, economical resources are one of the most significant determining. So, the results may not be the best but at least the cheapest from the available good ones.
- It was planned to also design a residual water system for these new anti-seismic houses, but then this dissertation would have pretended to take a range too wide for a single project, with very different problems set out.

3. INTRODUCTION TO NEPAL

Economic difficulties, a Maoist uprising and a civil war, the decline of a centenary monarchy and the creation of a democratic federal republic are few of the last events that have marked Nepal in its last decades. However, earthquakes that hit Nepal on 25th April and 12th May in 2015 were the worst crisis suffered in the country; there were more than 8500 of dead people and, therefore, devastation was spread all-over the country.

Population	*31 milion*[1]	Unemployment	*3,1%*
Area	*147.181 km²*	Inflation (CPI)	*7,2%*
Life expectancy	*67 years old*	Public Debt	*28,7% of GDP*
Alphabetisation rate of adults	*57%*	GDP[2] (PPP)	*$70,1 billion*
Average age	*23 years old*	Density	*30 person per km²*

Table 1. Quick quantitative characteristics about Nepal

Nepali's building methodology is entirely distinct from Spanish or even Occidental procedures. This is caused because its different reality, conditioned to three country bases: environment, economy and society.

- **Environment**

Nepal is located in South Asia between China in the north and India in the south, east and west. Although being surrounded of these big Asiatic countries, Nepal is not hidden from the world, because from the east to west of the country, Nepal is placed in the Himalayan Range, the higher range all-over the world and probably the most admired and visited mountains. The country can be divided into three main geographical regions: Himalayan region, mid hill region and Terai region. The highest point in the country is Mt. Everest (8,848 m) while the lowest point is in the Terai plains of Kechana Kalan, in Jhapa (60 m).

[1] Estimation of 2014

[2] Gross domestic product (Purchasing Power Parity)

Figure 1. Nepal physical map, by OnTheWorldMap

Another big influence in Nepali's environment are the natural disasters such as earthquakes and floods caused for their monsoon season. Monsoon season is not exact on calendars, but usually starts at May ending/June beginning and finishes at September beginning/ending. It covers the entire country with light daily rains during mostly evening and night but with some heavy rains that may cause floods in the area, at least one per year.

Regarding to earthquake's hazard, Nepal is located in a considered potentially seismic area. The country lies towards the southern limit of the diffuse collisional boundary where the Indian Plate underthrusts the Eurasian Plate and, as consequence of the activity of this border, Himalayan Range gets higher year by year.

But, although the marvellous paradise for mountain lovers, environmental issues in Nepal are numerous and terrifying. Mountain biodiversity is suffering due to ecological fragility and instability of high mountain environments, deforestation, poor management of natural resources, and inappropriate farming practices. Also factors for loss of biodiversity include landslide and soil erosion, pollution, fire, overgrazing, illegal trade, hunting and smuggling.

- **Economically**

Nepal is one of the 48 considered developing countries or least developed countries[3], whose are defined as nations or sovereign states with a less developed industrial base and a low Human Development Index (HDI) relative to other countries.

However, it has been progress in exploiting Nepal's natural resources, tourism and hydroelectricity. In the early 1990s, one large public sector project and a number of private projects were planned; some have been completed. The most significant private sector financed hydroelectric projects currently in operation are the Khimti Khola (60 MW) and the Bhote Koshi Project (36 MW). The project is still undergoing and has dependency on China, India and Japan to take the further steps.

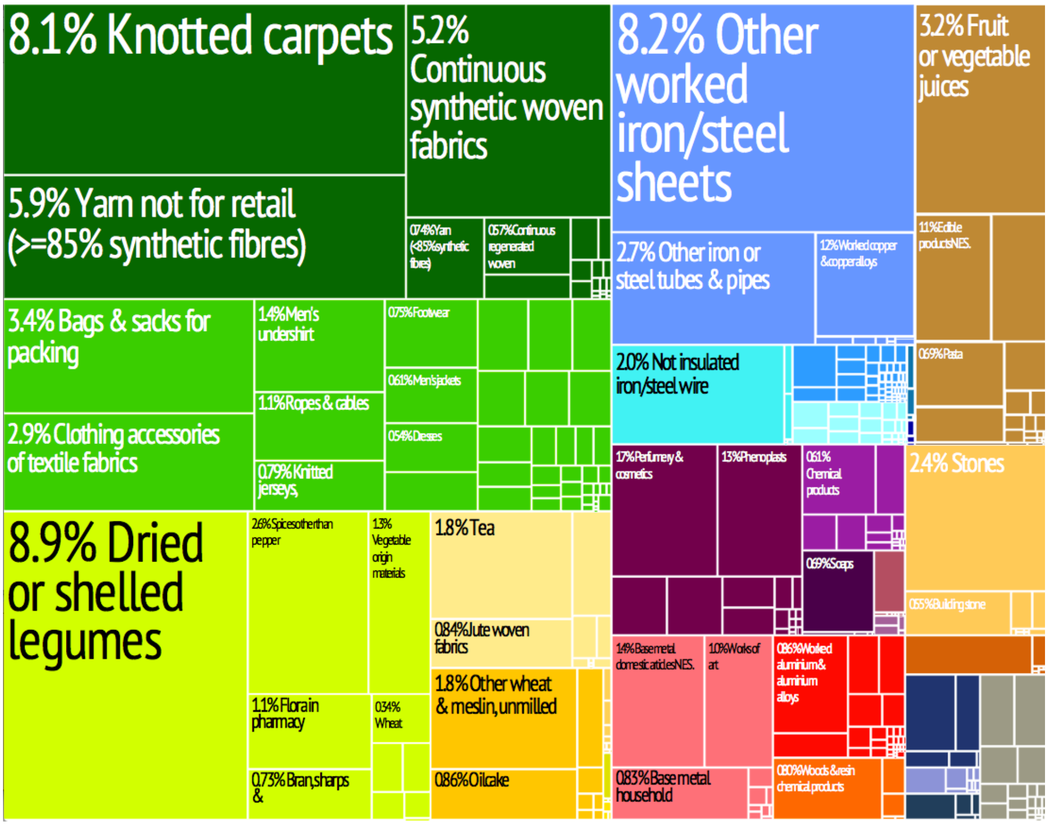


Figure 2. Proportional representation of Nepal's exports, by MIT Media Lab

The economy in Nepal has been detected that lacks the entrepreneurial dynamism, strongly needed for more stable economic growth and long-term development. The state

[3] According to “The Least Developed Countries Report 2016” by United Nations Conference on Trade and Development (UNCTAD)

continues to hinder private-sector development, and political instability further weakens the capacity to implement economic reform or create a stable development environment.

- **Socially**

About the national psychology of Nepal, has to be remarked the concepts of “cast” and “status”. Both concepts have contributed in creating a social system strictly defined by hierarchy and deference; a cast determines the status of a person, and also its studies, marriage, range in the family and its interaction with other people.

Regarding to religion beliefs, Nepali people are surprisingly flexible, pragmatic and tolerant; almost any conflict between religions exists. And even is the birthplace of Siddhartha Gautama (Buda), 81% of population is Hindu, and just a 9% is Buddhist[4].

In politics, Nepal has been very unstable for the last decades. Monarchy was arraigned to Nepal for the past 240 years, so Maoist people got in a national revolution that cost thousands of lives. These Maoist revolutionaries, got into the government of Nepal by winning in a democratic process and they abolished the monarchy system. As fist measure, they redacted a new Constitution, not valid until 20/9/15.

Afterwards, right now the main problem of Nepali society is another: the overpopulation. Overpopulation in a developing country is a massive weapon for its development, because if more people resides in the country and families get higher, then the money needed to pay would be also higher.

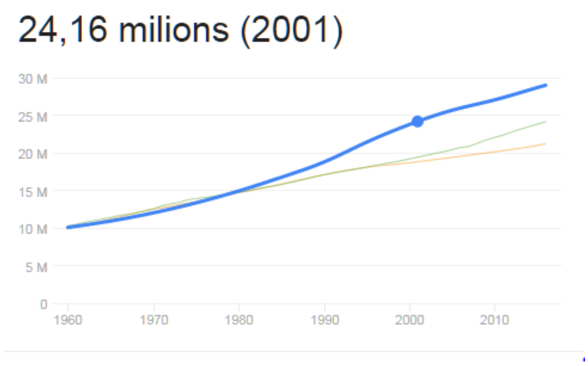


Figure 3. Nepal's increment of population from 1960, by Banc Mundial

[4] Statistics according to national census of 2011

From 2001 to 2014, population has passed from 24M people to 31M. This growing rate is hundred percent unsustainable, and it is caused because:

- High birth rate
- Falling death rate
- Religious and social belief
- Lack of education
- Early marriages
- International Migration incoming
- Lack of family planning service

3. NEPALI TRADITIONAL ARCHITECTURE

Nepal has a really valorised and important heritage in architecture, mostly propelled because its ancient different monarchies. Although earthquakes in 2015 hit heavily in this trade (specially the temples in the Durbar Squares of Bhaktapur and Kathmandu), there are still two big differenced categories of buildings:

- Vernacular
  - Newari housing
  - Tharu housing
- Religious
  - Hindu temples
  - Buddhist monasteries

But, although buildings styles have separate outlines, it is possible to unite them in some of their construction details. The main features of the Nepalese traditional architecture are:

- Use of natural brickwork consisting of a few layers of natural stones – large pebbles of broken stones
- Low ceiling, actually used to protect the inmates from the cold weather outside
- The extensive use of woodwork
- The lack of smoothness in texture
- A single or double row of posts supporting the upper brickwork with the doors consisting of an interior frame and an exterior framework which are joined

together by four wooden ties. These are printed together with wooden nails and there are small and narrow windows and fine external designs flaunting rich artistry.

In the following sections, are going to be explained all these architecture styles and the typical Nepali architectural elements.

3.1 VERNACULAR HOUSES

3.1.1 NEWARI STYLE

Figure 4. Newari typical face

The newa architecture is an indigenous style from Newar or Newah civilization, the historical inhabitants of Kathmandu Valley and its surrounding areas in Nepal. They were the creators of Nepalese historic heritage and civilization, and its lifestyle stills remaining in the area quite unchanged, so does its traditional building design.

Representative Newari building elements

1. Courtyard or Chowk providing both security and privacy and a single narrow and low gateway
2. Vertical room arrangement independent on the size of the house
3. Symmetric facades to a central axis with a central entrance door barred with massive wooden planks
4. Windows closed by fine wooden latticework
5. “San Jhya” window in the main living room as the most important communication to the street besides the door
6. Pitched roof
7. Burnt brick and timber as the most commonly used materials
8. Simple interior furnishing and decorations contrasting to lavish facades
9. Foundations built with few layers of natural stones with clay mortar

Table 2. Representative Newari building elements

The principal esthetical emblem characteristic of this design is the fine brickwork and woodcarving on their facades and walls. Referring to urbanism disposition, its main characteristic is the quadrangular disposition of houses forming courtyards or rows leaning houses one in front of the other.

Figure 5. Newari Courtyard

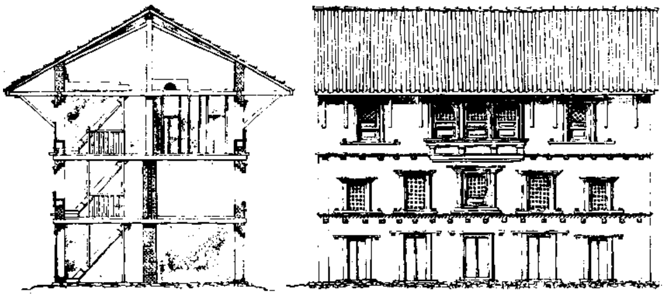


Figure 6. Skeleton of Newari house, by Sujanshil Pakar

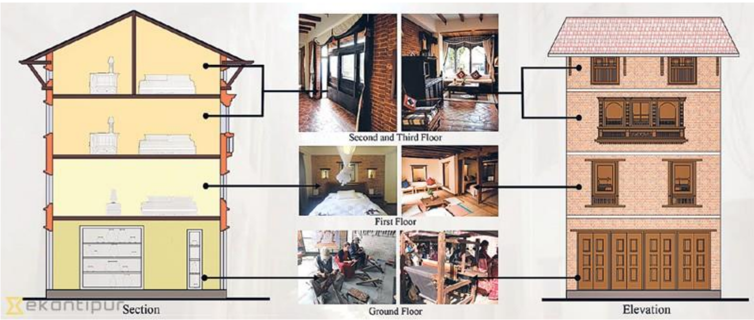
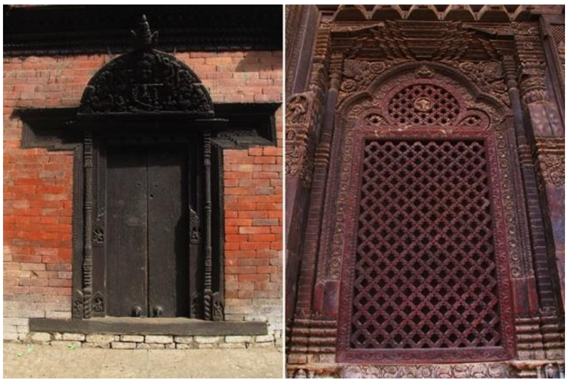


Figure 7. Disposition of Newai houses, by Kathmandu Post



Doors and windows

3.1.2THARU STYLE

Tharu people are an ethnic group indigenous to the southern foothills of the Himalayas, mostly of them living in the Nepal Terai.

They were the natural jungle people of the plains, secluded away for centuries until the jungles were no longer safe from outsiders. Most of them prefer living in *Badaghar* called longhouses with big families of many generations, sometimes 40-50 people. All household members pool their labor force, contribute their income, share the expenditure and use one kitchen.

Their houses are built entirely using natural materials such as reed poles for walls, mud for facing and thatch for roofing. As these houses are very vulnerable to be damaged because weather conditions, they become “temporary”: every year their roofs and their facings have to be renewed.

Emblematic/representative Tharu building elements

- Houses entirely built using natural materials
- Main structure and horizontal bands done by big bamboo stalks, with vertical reed poles along the wall perimeter (working as wall rigid structure)
- Facing executed with mud and excrement mixed
- Roofs made by GI sheets covered with thatch
- Clay-baked animal motifs like tigers and rhinos used in place of godly images, often drawn in their facades

Figure 8. Walls

Figure 9. Bamboo structure

Figure 10. Tharu village

3.2 CHARACTERISTIC ARCHITECTURAL ELEMENTS

3.2.1 PAGODA PATTERN

Figure 11. Pagoda roof of Nyatapola temple, Bhaktapur

The pagoda pattern of monuments and buildings means the style of having more than one roof with a broader base and gradually narrowing tops. The roof of this style of building typically crowned by triangular spires surrounding and lattice windows are used which gives look in outermost real bell shape.

This roof style was introduced in Nepal from the beginning of the thirteen century, during the Malla Dynasty, and later was taken to China by Araniko and others, not backwards as it is commonly thought. The most popular sites to observe these pagoda patterns are Kathmandu's Basantapur Durbar Square area, Taleju temple of Basantapur, Kashthamandap and temples of around, Patan Durbar Square area, Kumbheswor temple, and many temple of around, Bhaktapur Durbar Square area, popular Nyatapola temple and Datatraya temple, others Pashupatinath and Changu Narayan temples.

Figure 12. Pagoda roofs in Durbar Square, Kathmandu

3.2.2 STUPA PATTERN

Figure 13. Bauddhanath Stupa, Bauddha

The Stupa Pattern of monuments and temples it is known as mainly hemispherical round shape in bottom and segmented part to part round up to top, decorated with images pattern of different sects of Buddhism atop. The main base of ground is always in mandala shaped of every Buddhist stupas and pair of big eyes in square of main body which can be observed from all side easily. Nepal's most popular sites to see stupas are Bauddhanath, Swoyambhunath and many other stupas or Chhortens of Kathmandu valley.

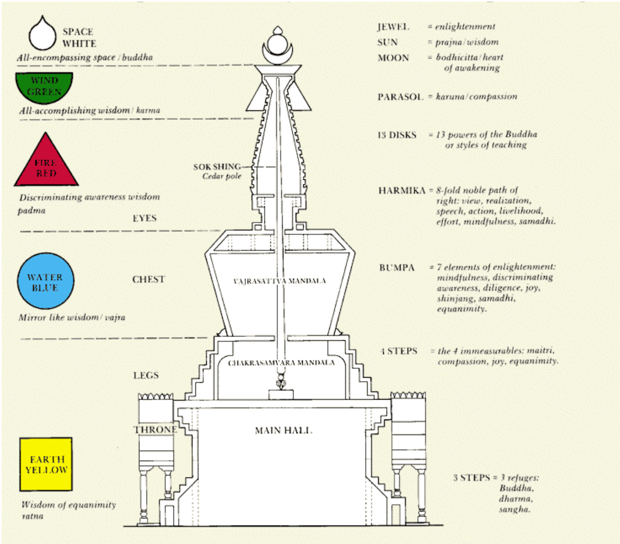


Figure 14. Stupa symbology, by Wikipedia

3.2.3 SHIKHARA PATTERN

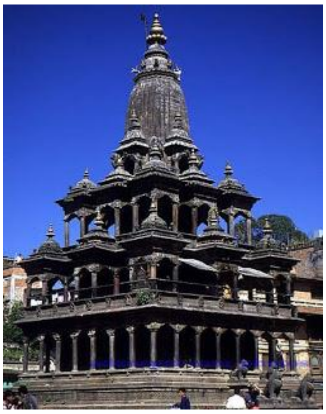


Figure 15. Krishna Mandir, Patan

The tall and pyramidal Shikhar Pattern on nepali temples is very common monuments of Hindu shrine. It consists in five to nine perpendicular divisions or sections at the outer part of such architectures, forming a high pyramidal or curvilinear tower with Gajurs at the top of each section. They are broader at the lower portion and becomes narrower at the top.

In Nepal this type of construction can be seen at Patan Durbar Square area which is known as famous Krishna temple as well some are at Pashupatinath temple area and some Hindu temples of Kathmandu valley.

Figure 16. Bungamati temple and Bhaktapur temple

3.2.4 THANGKA PAINTING

Figure 17. Thangka representing Buddha life

Thangka or thanka paintings are authentic from traditional Buddhist culture and religious artistic handwork of Nepal, which reflects real Buddhism philosophy by its unique art. They are painted on cotton or silk appliqué, usually depicting a Buddhist deity, scene, or mandala.

These paintings still handmade nowadays. It's usually related to Tibetan art, but there are many different variety and qualities of thangka paintings available in the Kathmandu Valley's thank shops as well in Pokhara. Some expensive and master piece images painted with the colour mixed of gold and silver as well long time hard work.

Figure 18. Nepali artisan paiting by hand a Thankga paiting, Kathmandu

EARTHQUAKE ENGINEERING

4. INTRODUCTION TO SEISMICITY

An earthquake or seism is a shaking phenomenon rough and temporary on Earth's surface, caused because a release of accumulated energy in form of seismic waves.

The main common causes for an earthquake are:

- Activity on geologic faults
- Friction at tectonic plate borders
- Volcanic activity
- Nuclear subterranean detonations
- Landslides
- Mine blasts

And the main common consequences are the following:

- Ground shaking
- Differential ground settlements
- Land and mud slides
- Soil liquefaction
- Avalanches
- Ground displacement along a fault
- Tsunamis
- Falling objects
- Building collapse

From all these causes and consequences, the main object of this study is the building collapse because of seismic activity on tectonic plate borders, but first it is recommendable to review some basic concepts on seismicity.

4.1 SEISMIC PROPAGATION

Seismic movement is spread from hypocentre in same behaviour as sound movement: in elastic waves named *seismic waves*.

The full elastic seismic wavefield that propagates through an isotropic Earth consists of a P-wave component and two shear (SV and SH) wave components.

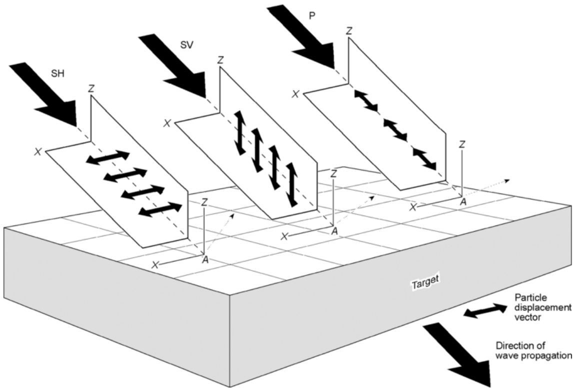


Figure 19. Distinction between the three components of an elastic wavefield, by Petrowiki

Earthquakes create distinct seismic waves, with different velocities, medium of transmission and direction. As big groups, can be distinct two different categories: body waves and surface waves.

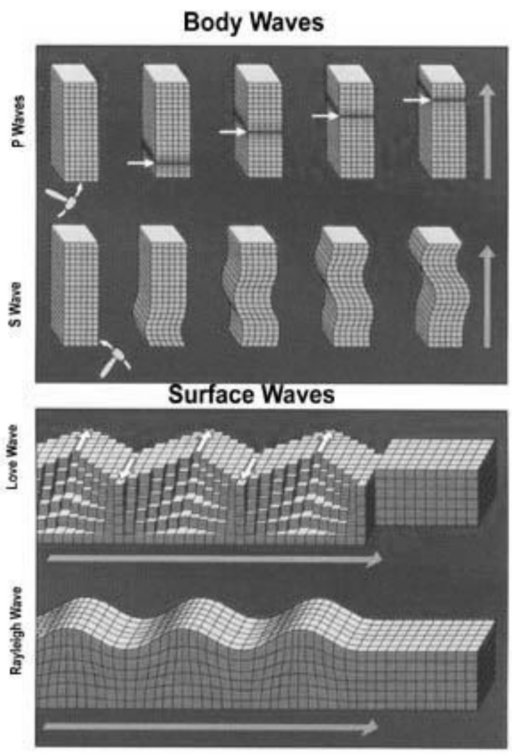


Figure 20. Difference on seismic propagation, by Petrowiki

4.1.1 BODY WAVES

Travel through the interior of the Earth along paths controlled by the material properties in terms of density and modulus (stiffness). The density and modulus vary according to temperature, composition, and material phase.

Primary waves

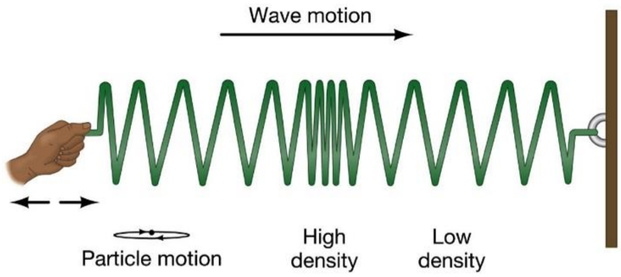


Figure 21. Primary wave schema, by Google images

Longitudinal waves, primary waves or P-waves are compressional waves that are longitudinal in nature. They travel at 8 to 13 km/s in same direction as particle vibration, resulting the first to arrive at seismograph stations (hence the name “primary”). They travel through any type of material.

$$v_p = \sqrt{\frac{\lambda + 2\mu}{\rho}} = \sqrt{\frac{\kappa + 4\mu/3}{\rho}}$$

Secondary waves

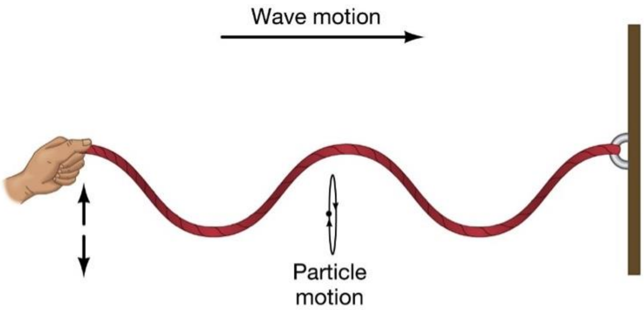


Figure 22. Secondary wave schema, by Google Images

Transversal waves, secondary waves or S-waves are shear waves that are transverse in nature. They travel at 4 to 8 km/s perpendicularly to particle vibration waves, resulting the second ones to arrive at seismograph stations (hence the name “secondary”). They can only travel though solids, because fluids do not support shear stress.

$$v_s = \sqrt{\frac{\mu}{\rho}}$$

This type of body waves is the cause of oscillation during seismic movement, so in consequence are the more damaging ones.

4.1.2 SURFACE WAVES

Seismic surface waves or L-waves travel along the Earth's surface at approximately 3,5 km/s. This type of waves results from interaction between P and S waves, and spread along the discontinuity surface of earth surface's interphase (earth-air, earth-water).

This type of waves can be the most destructive type because its long duration and large amplitude. They're the ones who cause damages in buildings.

Rayleigh waves

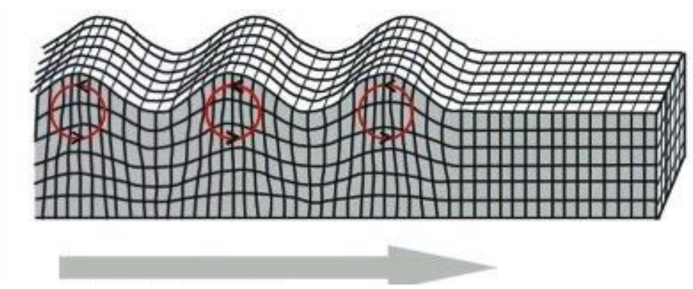


Figure 23. Rayleigh wave schema, by Google Images

Rayleigh waves or gound roll are surface waves that travel as ripples with motions, similar to waves on the surface of water. In the layered medium (like the crust and upper mantle) the velocity of the Rayleigh waves depends on their frequency and wavelength.

This type of surface waves creates particle displacements in the vertical plane.

Love waves

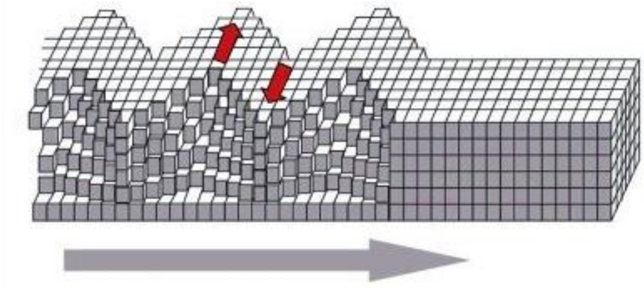


Figure 24. Love wave schema, by Google Images

Love waves are horizontally polarized shear waves (SH waves), existing only in the presence of a semi-infinite medium overlain by an upper layer of finite thickness. The amplitude of this motion decreases with depth.

This type of surface waves creates particle displacements in the horizontal plane, so changes the shape of the rocks it passes through.

5. SEISMIC RESPONSE OF BUILDINGS

Surface waves, explained previously, attempts to the base of the buildings because its shaking movement along the ground surface.

These S-waves are the main problem for earthquake vulnerability in buildings, because these ground movements force the lower part of the building to move along on a lateral plane, while the upper part of the building has a tendency on staying at the original position, because of Newton's First Law[5].

However, as walls and columns are connected to roof and upper floors, the lasts are dragged in with the same movement. This phenomenon is due to *inertia force*.

[5] *"In an inertial reference frame, an object either remains at rest or continues to move at a constant velocity, unless acted upon by a force"* Newton's first law of motion, often referred to as the *Law to inertia*.

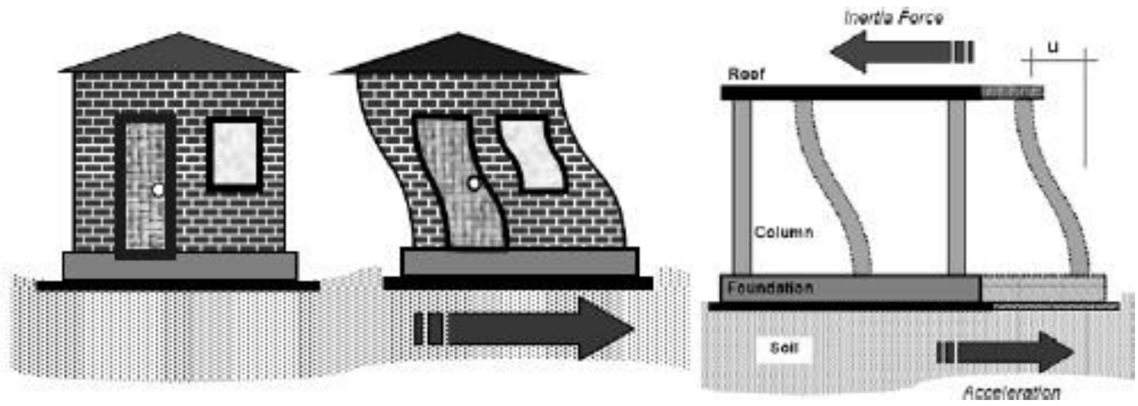


Figure 25. Inertia force schema, by Academia

Consequently, thanks to Newton's second law of motion[6] and considering a simple structure of columns-roof, the mass of roof (m) will experience an acceleration (a) because of an inertia force equal to m·a, with a direction opposite to acceleration direction.

$$Inertia\ force\ (F) = Mass\ of\ structure(m) \cdot Acceleration\ (a)$$

Therefore, this concludes that as much mass has the building, higher will be the inertia force and, consequently, higher will be the shaking and bigger will be the structural damages. To prevent it, earthquake engineering suggests lightness of the building and its elements (especially on the upper parts), and similarly it suggests the structural elements and their mutual connections to be designed properly in order to safely transfer these inertia forces through them.

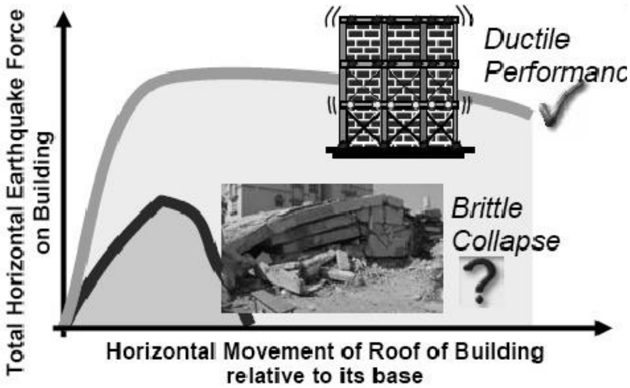
5.1 DUCTILE AND BRITTLE COLLAPSE

Structural and earthquake engineering must consider always the maximum safety in a structure at the whole range of possibilities and situations in its lifetime, including the one with worse consequences and less options: its collapse.

[6] "*In an inertial reference frame, the vector sum of the forces* F *on an object is equal to the mass* m *of that object multiplied by the acceleration* a *of the object: F = m·a*" Newton's second law of motion.

Considering the structure has came in collapse, the main objective is to protect the possible victims giving them easy signals or evidences of failure and/or time for run away from the building. For achieving this behaviour, the structure must behave as a ductile material.

Ductile materials are the ones who under the action of a force deform plastically, whose cracks resists further extension unless applied stress is increased; while, brittle materials, collapse or crack.



5.2 EARTHQUAKE VULNERABILITY OF TRADITIONAL NEPALI BUILDINGS

In Nepal, every fifty to hundred years occurs an earthquake. This is caused because the country lies over an area where the Indian plate collides with the Eurasian plate. But, even so, has taken many years to seismographs and earthquake engineering to arrive to Nepal.

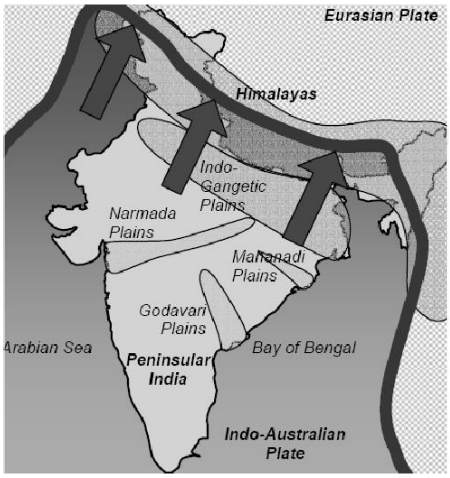


Figure 26. Nepali tectonic plate disposition, by Minke

Decades ago, the only method to predict an earthquake was an astrological one, by observing planets, stars and their positions. Surprisingly, it worked in couple times, but just getting right at an approximate date, not even place or time.

However, this revealed the fact that Kathmandu people had the knowledge of safe evacuation and precautionary actions if early warning was possible. When there was an earthquake hazard incoming, elders were told to sleep at first floor, and young were asked to sleep with their parents on the ground floor, to get rid of earthquake; even some of them slept on an open space next to the house. In fact, this protocol was just thought because the principles of escape and evacuation, but unknowingly, they were applying a good procedure for an earthquake emergency.

5.2.1 NEWARI HOUSES

As a continuity of vulnerability, are going to be announced the vulnerable and resistant items of the ancient architecture Newari.

Vulnerable items:

- All main walls are brick masonry walls, a brittle material
- The use of mud mortar in masonry walls
- The topmost part contains a timber roof with mud tiles.

Resistant items:

- The inner partition walls are made of timber, so such partitions are lighter than the brick masonry.
- The thickness of the major walls is gradually reduced as the building goes higher.
- Ring ties around the building on the top of the wall to tie the roof to the wall
- Thickness of masonry wall ranges from 28cm to 70 cm, and occasionally expands to 2 meters
- Simple, symmetric and not so high plan.
- Doors and windows small in comparison to the overall length and height of the wall.
- Mud mortar cracks and helps to displace wall thus absorbing the thrust, causing partial collapse and preventing the total collapse of the building.

Some examples:

Figure 27. Houses in Bhaktapur affected by the seism

6. SEISMIC RESPONSE OF SOILS

As commented in first term, seismic waves are elastic waves, so Earth material must behave elastically to transmit them. The degree of elasticity determines how well they are transmitted.

By the pressure front expanding from an underground explosion, or by an earthquake shear rupture, the surrounding Earth material is subjected to stress (compression, tension and/or shearing), and as consequence, it undergoes strain. Examples would be changes in volume and/or distort of shape. But, in case the material was inelastic (plastic, ductile) this deformation would remain while elastic behaviour means that the material returns to its original volume and shape when the stress load is over.

Within its elastic range the behaviour of the Earth material can be described by Hooke's Law, which states that the amount of strain is linearly proportional to the amount of stress. Beyond its elastic limit the material may either respond with brittle fracturing or ductile behaviour/plastic flow.

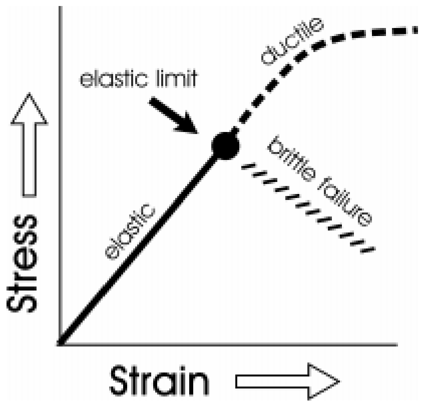


Figure 28. ***Relationship between stress and strain, by Minke***

Ground rupture

Shaking and ground rupture are the main effects created by earthquakes, principally resulting in more or less severe damage to buildings and other rigid structures. The severity of the local effects depends on the complex combination of the earthquake magnitude, the distance from the epicenter, and the local geological and geomorphological conditions, which may amplify or reduce wave propagation. The ground-shaking is measured by ground acceleration.

Specific local geological, geomorphological, and geostructural features can induce high levels of shaking on the ground surface even from low-intensity earthquakes. This effect is called site or local amplification. It is principally due to the transfer of the seismic motion from hard deep soils to soft superficial soils and to effects of seismic energy focalization owing to typical geometrical setting of the deposits.

Ground rupture is a visible breaking and displacement of the Earth's surface along the trace of the fault, which may be of the order of several meters in the case of major earthquakes. Ground rupture is a major risk for large engineering structures such as dams, bridges and nuclear power stations and requires careful mapping of existing faults to identify any which are likely to break the ground surface within the life of the structure.

Material or Geologic Formation	Bulk Modulus in 10^9 Pa	Shear Modulus in 10^9 Pa	Density in kg m^{-3}	Poisson Ratio	v_p in km s^{-1}	v_s in km s^{-1}	v_p/v_s
Air	0.0001	0	1.0	0.5	0.32	0	∞
Water	2.2	0	1000	0.5	1.5	0	∞
Ice	3.0	4.9	920	-0.034	3.2	2.3	1.39
Clastic sedimentary rocks					(1.4-5.3)		
Sandstone	24	17	2500	0.21	4.3	2.6	1.65
Salt	24	18	2200	0.17	4.6 (3.8-5.2)	2.9	1.59
Limestone	38	22	2700	0.19	4.7 (2.9-5.6)	2.9	1.62
Granite	56 (47-69)	34 (30-37)	2610 (2340-2670)	0.25 (0.20-0.31)	6.2 (5.8-6.4)	3.6 (3.4-3.7)	1.73 (1.65-1.91)
Basalt	71 (64-80)	38 (33-41)	2940 (2850-3050)	0.28 (0.26-0.29)	6.4 (6.1-6.7)	3.6 (3.4-3.7)	1.80 (1.76-1.82)
Peridotite, Dunit, Pyroxenite	128 (113-141)	63 (52–72)	3300 (3190-3365)	0.29 (0.26-0.29)	8.0 (7.5–8.4)	4.4 (4.0–4.7)	1.8 (1.76-1.91)
Metamorphic& igneous rocks					(3.8-6.4)		
Ultramafic rocks					(7.2-8.7)		
Cenozoic			1500-2100	0.38-<0.5	(0.2-1.9)		2.3 - 8
Cenozoic water saturated			1950	0.48	1.7	0.34	5
Cretaceous & Jurassic			2400-2500	0.28-0.43			1.8 – 2.8
Triassic			2500-2700	0.28-0.40			1.8 – 2.5
Upper Permian			2000-2900	0.23-0.31			1.7 – 1.9
Carboniferous				0.31-0.35			1.9 – 2.1

Table 3. ***Typical values (averages and/or approximate ranges) of elastic constants, density, Poisson's ratio and seismic wave velocities for some selected materials, unconsolidated sediments, sedimentary rocks of different geologic age and igneous/plutonic rocks***

An earthquake induces undrained conditions into a soil, meaning that due to the application of the cyclic and rushed load of an earthquake occurs an increase of the pressure in the pores between the particles, which can cause the tendency of effective stresses to zero; it is a loss of tension in the contact between the particles, and this causes a transformation in the state of the soil, since it takes the form of a suspension.

This phenomenon is called liquefaction and occurs mainly in saturated sandy soils; It has also been observed in cohesive soils, but requires more energy to be produced, because cohesion prevents them from liquefaction.

6.1 SOIL LIQUEFACTION

Liquefaction is a natural process where certain types of soil lose brusquely its mechanical resistance because of a rapid dynamic load (such as an earthquake). The loss of soil's mechanical resistance implies that it acts momentarily as a fluid-like mode, being able to migrate generating important deformations in the terrain. Soil liquefaction may cause rigid structures, like buildings and bridges, to tilt or sink into the liquefied deposits.

Liquefaction is generated mainly in sandy soils and silt-sands saturated in water, usually located near rivers, beach shores or other bodies of water, or also in those soils where there is a very superficial phreatic level. In addition, it happens in the soils with low compaction as, for example, those lands where before existed lakes, lagoons and wetland areas.

When an earthquake occurs, the vibration raises the water pressure in soil's porous and, if it reaches equal or exceeds the force of contact between the grains, the resistance of the soil reduces to zero, undergoing to liquefaction. In this case, the load capacity of the ground becomes null and the soil during the shaking behaves as a liquid, what causes that any structure cemented on it will sink or suffer differential settlements.

The condition factors that contribute to occur liquefaction phenomenon are the following:

- Soil's origin
    - Soils deposited from fluvial, coastal and Eolic processes settle easily and their grains are unlikely to be compacted, they can liquate easily.
    - Glacial deposits are generally quite dense and have lower probability of liquefying.
    - Rock soils are not in liquefaction risk at all.

- Distribution of grain size
    - Uniformly graduated sand, of very thick grain is more likely to liquefy
    - Thin slime sand and gravel con liquefy under cyclical loads very severe

- Depth of groundwater level
    - The closer you are to the groundwater level, the greater the likelihood that liquefaction can occur

- Soil's age
    - Young soils (less than 3,000 years) are weak and non-cohesive, so that they are more likely to liquefy compared to those older ones where they have acting processes of compaction and natural cementation.

- Amplitude and length of earthquake's vibration
    - Soil liquefaction increases with the magnitude and duration of the earthquake.
    - Small earthquakes will liqueur only the soils closest to the epicentre, while a seism of magnitude greater it will be possible to recognize liquefaction at very large distances.

- Soil's depth
    - Tension between particles increase as the pressure of the coating increases (to more depth). The greater it is this tension, the lower will be the likelihood of liquefaction.
    - In general, liquefaction occurs at depths smaller than 9 m and, rarely, at greater than 15 m.

7. ANTI-SEISMIC BUILDING SYSTEMS

Applying all knowledge studied in previous sections about earthquake, soils and buildings, is made the following catalogue of building recommendations and tips for building a good anti-seismic house in Nepal's country, considering the most suitable and affordable house type for the area: a single storey house of low strength masonry using local stones and mud mortar.

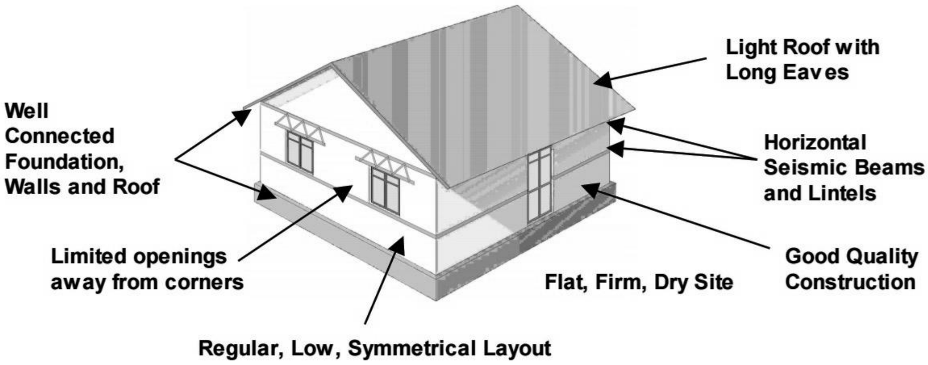


Figure 29. Summary of an accurate anti-seismic house, by CAESI

7.1 EMPLACEMENT

A bad decision at the very first moment of a construction, like a wrong emplacement selection, can guarantee to a structure the partial or total collapse during an earthquake.

Therefore, to properly select the best site for a building, must be avoided the following geological/geographical settings:

a. Step and unstable slopes
b. Areas susceptible to landslides and rockfall
c. Loosely filled grounds
d. River banks
e. Visible, permanent, deep and active faults

In addition, the best distance between a house and a tree or with an adjoining house, it is preferably to be at least equal to the height of tree or house, whichever is larger.

7.2 LAYOUT

In a building, in order to suffer as less torsional stress as possible, its plan shape design becomes crucial.

Regular shaped buildings are the most robust and resistant to torque; thus best plans profiles are the square, the rectangular or the circular. In case it's planned to build a complex shaped building, it is correct to do it as long as it is subdivided in simple modulus (four-sided or round) with a one-inch gap in between, considering a one storied house.

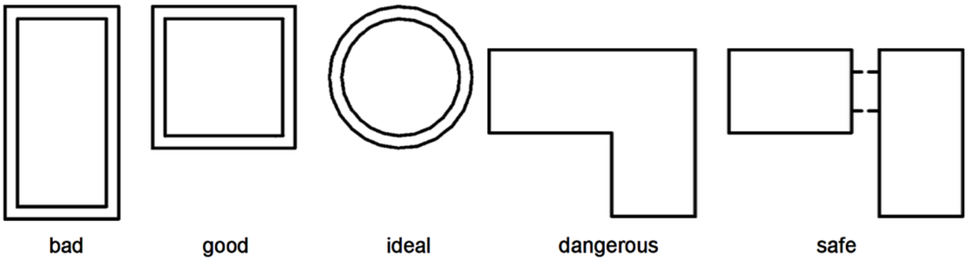


Figure 30. Plant dispositions, by Gernot Minke

Even it's a four-sided shape, must be specially avoided the narrow structures. They are very unstable at torque because it's different inertia between axes, and consequently a length of a house should not be more than 3 times its width.

Additionally, in order to give more robustness to the building, the best construction method is to build in a box type layout: small rooms of maximum 4,6m x 4,6m and floor, walls and roof tied-up with each other.

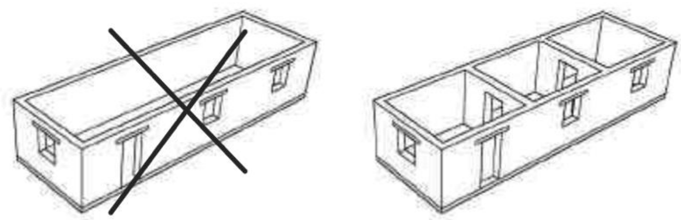


Figure 31. Correct narrowness, by ERRA[7]

7.3 FOUNDATION

[7] Earthquake Reconstruction & Rehabilitation Authority (ERRA)

A solid foundation is an essential must-have for an anti-seismic building. As the purpose of the foundations is to transfer the load of the construction to the ground, the weight of the structure must be suited to the load capacity of the ground.

This bearing capacity is related to soil stiffness, and consequently to foundation's depth: as softer as is a soil, lower will be the bearing capacity and, therefore, deeper should be the foundation. As standard parameters, in case of soft soil should be at least 90 cm, meanwhile for rocky areas, the minimum depth should be 45 cm. However, in both cases minimum width should be 75 cm or 10 cm wider from each wall side (whichever is higher from both).

In earthquake areas, generally, stepped strip footing should be adopted as foundation type, because it ties-up all loads in a monolithic behaviour and guarantees good results no matter which soil type there is below.

Foundation materials available for this type of housing is stone, brick and concrete block, but for any type, the upper structure (vertical reinforcement and walls) must also be correctly joined and anchored to the foundations.

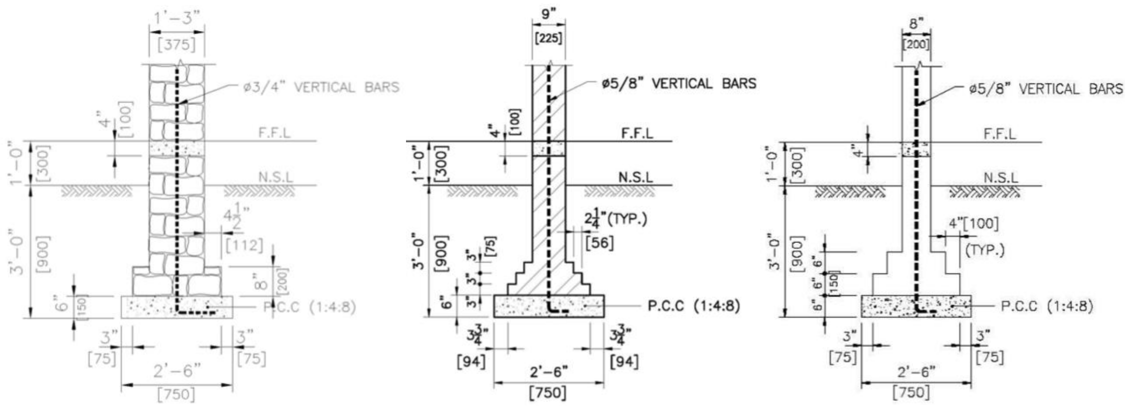


Figure 32. In that order: Examples of stone, brick and concrete block masonry foundations, by ERRA

7.3.1 PLINTH

To ensure the monolithic behaviour and solidness, adjacent to upper surface of foundation must be installed a continuous plinth with at least 30 cm high above ground level and with width equal to wall thickness. Best material for this element is reinforced concrete, but is common to build it with rubble random stone, bricks or concrete with large stone aggregates. This base wall will shelter the wall against splashing rain water.

Joints between foundation and plinth, as well as between plinth and wall, have to have a good bond in order to be able to transfer shear forces. They should be situated every 30 to 50 cm. The easiest solution is to integrate a vertical wooden rod and to create a rough plinth surface and, as it uses adobe for the walls, the mortar must have a very good adhesion and a high bending strength.

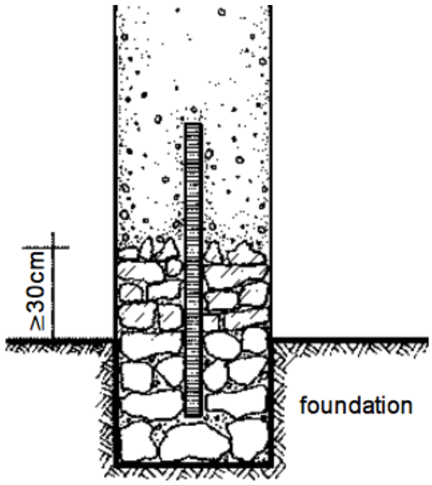


Figure 33. Joint between foundation, rammed earth wall and plith, by Gernot Minke

7.4 STRUCTURAL SKELETON

The structural skeleton for a single storey house of low strength masonry resistant to earthquakes must be as lighter as possible. Consequently, the best solution is to use wood for the entire structural framework and additional elements to reinforce the earthquake resistance.

7.4.1 RING BEAM

“Ring beams”, “seismic belts” or “horizontal bands” are the most important elements in adobe construction for preventing an earthquake collapse. This architectural ring consists in a wooden beam continuous along the perimeter walls of a building, which will make all parts of the wall at same level to act together and which must be able to take bending loads when there are lateral forces against the wall.

These wooden bands should be placed at all sill and lintel levels, at plinth level and at ceiling level.

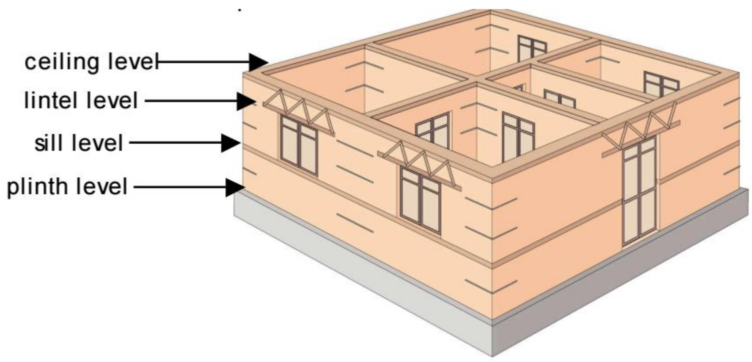


Figure 34. Ring beams best placements, by CAESI

7.4.2 STIFFENING MODULES

Stiffening modules are all the different architectural elements whose purpose is to strengthen a structural element against an earthquake effort.

As the triangle is the geometrical figure most stable against longitudinal loads, all stiffening modules will procure to triangulate the structure providing it with more robustness and resistance.

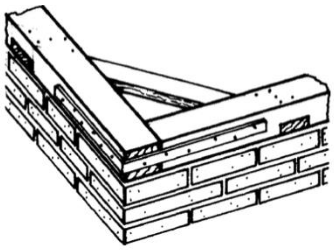


Figure 35. Stiffening module at a wall corner, by Gernot Minke

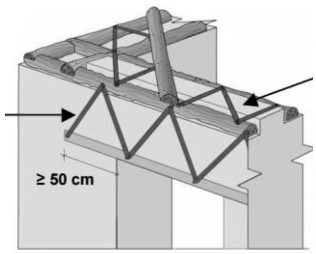


Figure 36. Stiffening module between lintel beam and roof beam, by CAESI

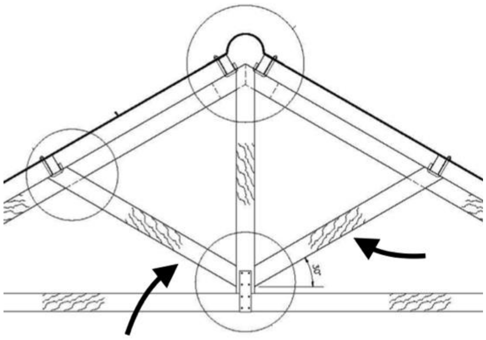


Figure 37. Stiffening beam at truss disposition, by ERRA

7.4.3 VERTICAL REINFORCEMENT

Another stabilizing method against horizontal forces is to use vertical roods of bamboo or wood inside the wall.

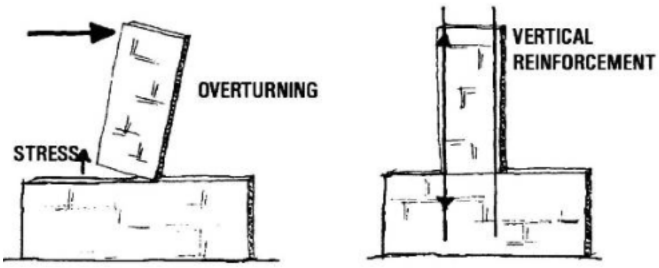


Figure 38. Vertical reinforcement schema, by ERRA

Best position for this vertical reinforcement is to place it at all corners, junctions of walls and next to all doors and windows. However, the space between two adjacent bars should be always less than 120 cm, so probably it would be more roods besides of the indispensables.

The accurate fixation of these elements is crucial. Lower end must be fixed in foundation and upper end must be fixed at a ring beam.

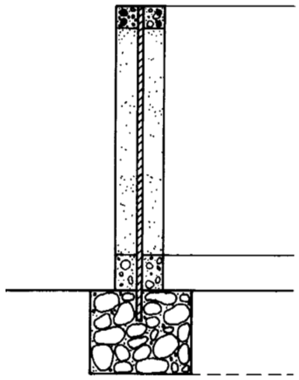


Figure 39. Rood's detailed fixation, by Gernot Minke

7.5 WALLS

In this local house type selected, walls are made by large stones and mud as mortar. The best recommendations to properly build this type of walls, should be taken the following rules:

- Minimum 50 cm of wall thickness or 8 times less than wall height, whichever is more restrictive.
- The stone used should be as hard, regular and free from defects as possible, in order to not adversely affect the integrity in use and will be visible in the completed work.
- The inner and outer whythes of the wall should be interlocked with though stones, stones of full length equal to wall thickness. They must be used every 60 cm.

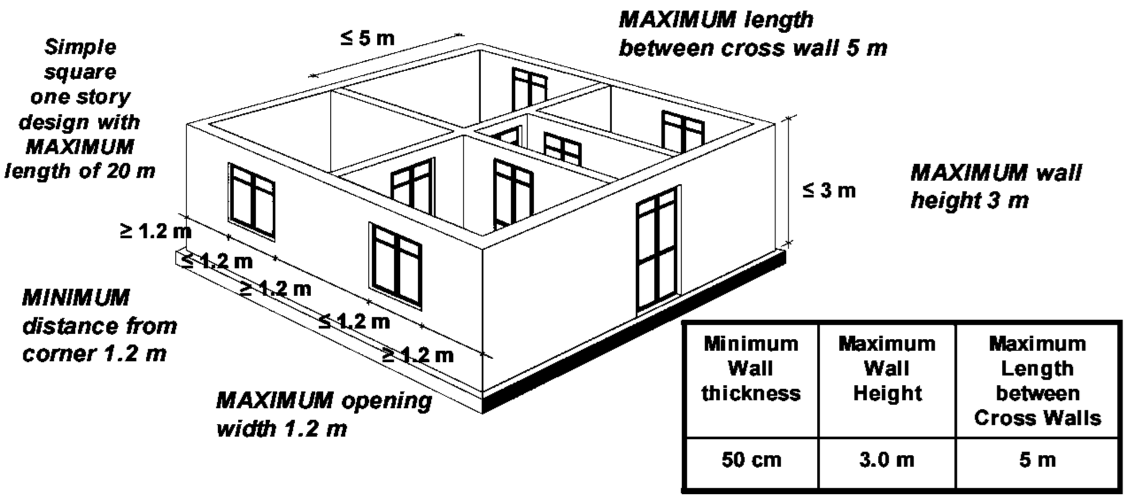


Figure 40. Graphical representation of a correct disposition, by CAESI

7.6 ROOF

As has been commented previously, in order to reduce the damages caused by the inertia force in the upper parts of a building, the roof has to be as light as possible, as well as resistant. Therefore, the best solution is to build a light roof structure with wooden or steel trusses and then covered with CGI sheets.

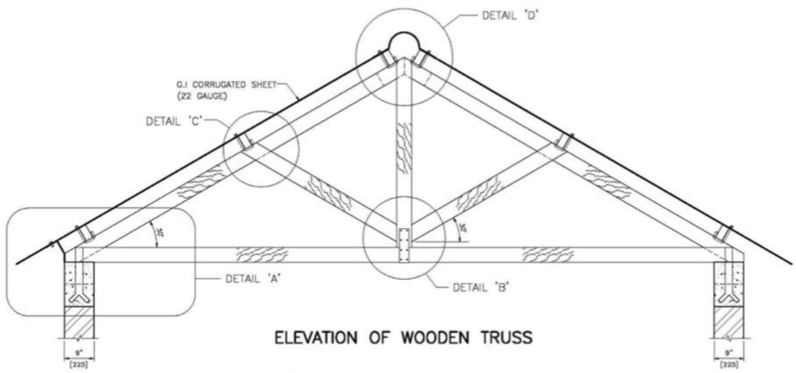


Figure 41. Details of a wooden truss suitable for small spans up to 12 feet, by ERRA

Hipped roofs (sloped at four sides) are preferable to pitched and flat roofs, although last ones are cheaper and easier to build. Even so, if a pitched or plat roof is used it should be strengthen with diagonal wires or wooden joists connected to roof rafters, which should be also bolted to the roof ring beam.

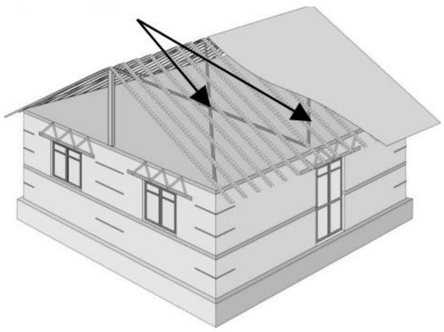


Figure 42. Diagonal reinforcement disposition, by CAESI[8]

On the other hand, there is another safe alternative to build roofs in seismic areas. As the frequency of the movements of roofs and walls differs during seismic activities, due to their different moment and weight, an smart solution is to separate the roof from the wall and have it resting on columns that are positioned inside or outside the wall. Thanks to it, the roof will be allowed to move independently and consequently not increase the horizontal forces against the wall.

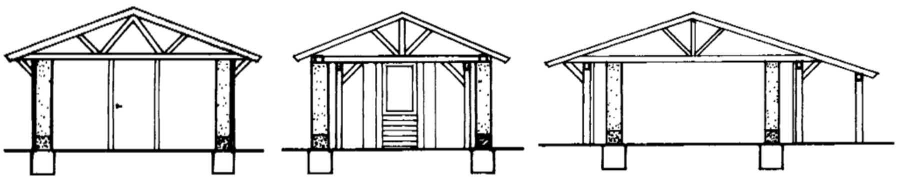


Figure 43. Examples of separated roof dispositions, by Gernot Minke

7.7 WINDOWS AND DOORS

Openings are very susceptible to cause big failures of resistance in a building. In fact, firsts cracks on an earthquake appear diagonally from window edges.

For guaranteeing the less destabilization possible, have to be followed the following recommendations:

- Lintels have to penetrate into the wall for at least 40 cm in order to achieve a good bond.

[8] Central Asia Earthquake Safety Initiative (CAESI)

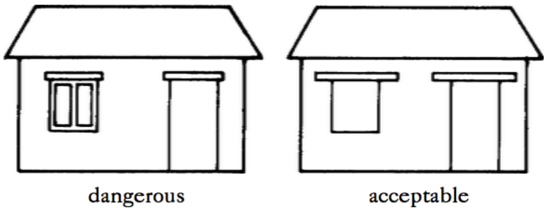


Figure 44. Correct lintels, by Gernot Minke

- Opening proportions should be higher than wider.
- The length of the windows should not be more than 1,20 m and not more than 1/3 of the length of the wall.
- The length of walls between openings must be at least 1/3 of their height and not less than 1 m.
- Distance between building corners and an opening should be at least 1,20 m.

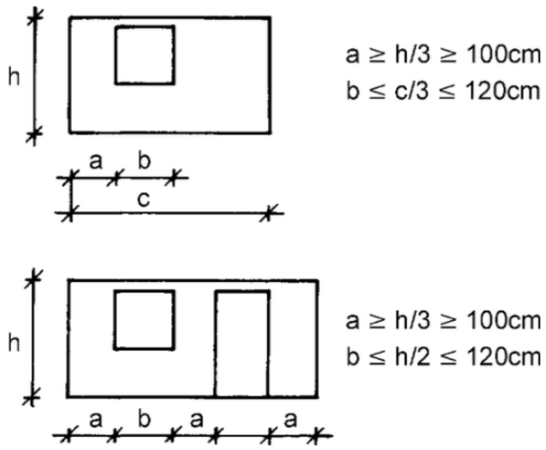


Figure 45. Recommendable proportions, by Gernot Minke

- The lintel level for doors and windows has to be always the same.
- The total length of doors and windows in a wall shouldn't be more than 50%.
- Doors must be opened towards the outside. Opposite the entrance door there should be a large window or another door, which acts as emergency exit.

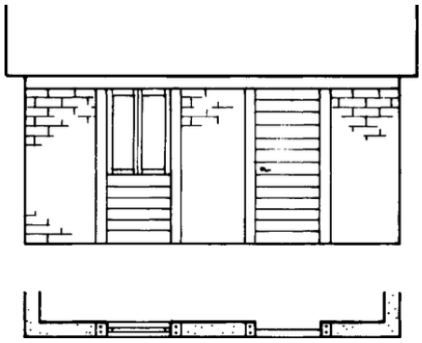


Figure 46. Proposal of a stabilised opening setting, by Gernot Minke

PRACTICAL CASE

8. INTRODUCTION

As it has been explained in the introduction of this study, one of the objectives for this dissertation is to apply all knowledge acquired by doing research about Nepal's building methods and about Earthquake Engineering in a real necessity.

The necessity chosen is to help Nepali people of a small village, Bhimphedi, to build again their houses destroyed or badly damaged after the earthquakes that hit Nepal on 2015. In order to be able to do this project, I got in contact with the architectural association *Base-A*, which was executing a re-building program called *AWASUKA* with partnership with *Amics del Nepal*, a Catalan NGO with cooperation programs in all disciplines.

In this program, my task assigned was to elaborate a geotechnical study of a new ward where are going to be build 7 new anti-seismic houses, and also to plan the best foundation system for them. Subsequently, all the following sections are going to develop the best solution for both tasks (which are closely dependent).

8.1 EMPLACEMENT

The emplacement for this project is the little village of Bhimphedi, in Nepal. Bhimphedi is located at a height of 1150m above sea level, in Makwanpur District of Narayani Zone (named because of Narayani river).

Figure 47. Nepal map with Makwanpur district on red, by Wikipedia

Figure 48. Makwanpur map with Bhimphedi in red

According to last census in 2001, Bhimphedi had 5742 of population (49% male and 51% female) and a total of 1107 houses. The 88% of population is dedicated to agriculture, following a subsistence method of generating food enough to feed the family and sell the surplus to neighbour villages.

It is located in the Mahabarat mountains, at the bottom of a valley with two rivers, Lamo Khola on the north and Rapati Khola on the south. It is one of the historical communities of the Makwanpur district. The capital of the district is Hetauda, located 20 km south of Bhimphedi.

Figure 49. View of Bhimphedi central village from surrounding hills

This community is distributed between the central commercial area, where are settled all sanitary services, its famous Market Street and most of educational services; and the rural area, spread in small “wards” along the closest mountain. Most of these small mountain areas (as Suping) are not accessible by motorised vehicles.

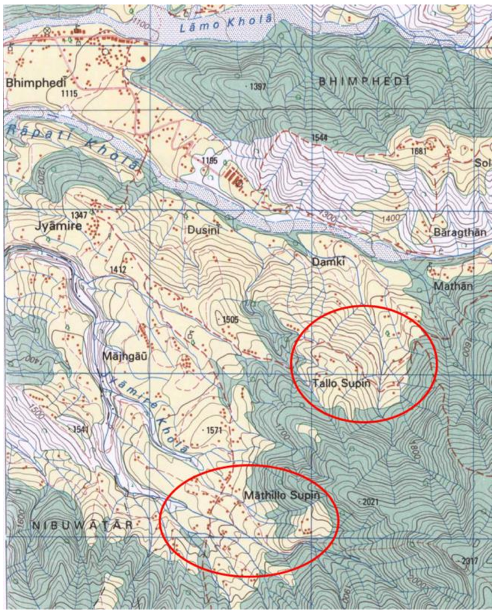


Figure 50. Map of Bhimphedi Area with Suping in red[9]

[9] Mathillo Suping = Upper Suping; Tallo Suping = Lower Suping

Suping is the rural ward number 7 located at 1500m, and is the exact emplacement for the future new houses of the project. The village is divided between upper Suping and lower Suping, but both are as a dormitory suburb; most of villagers go down to Bhimphedi to develop there their lives everyday.

Figure 51. Photographies of different streets in Bhimphedi

Figure 52. Photographies of different places in Suping

According to what constructions refers, at the moment there is a big “boom” for the trade. Just in Bhimphedi central area, right now there are more than 15 houses being constructed, and uncountable if it’s considered the entire municipality. It is basically happening because the damages caused by the two earthquakes in 2015.

During the last 20 years, *Amics del Nepal* has been working in this municipality, managing an orphanage and developing projects for the community. When the earthquake occurred, as *Amics del Nepal* was already volunteering in Bhimphedi, it was able to carry out a first emergency action for this community, thanks to having an expatriate resident in the orphanage. As this first emergency kit, were bought 300 stores for the habitants of the 9 wards that form the municipality. The final balance of material damages in this municipality was a total of 80% affected houses; so, as a result of it, it was born AWASUKA program.

8.2 AWASUKA PROGRAM

BHIMPHEDI AWASUKA

भीमफेदी आवासुका

Figure 53. AWASUKA logo

The name AWASUKA comes from 3 different Nepali words “*Aawaas Sudhar Karyakram”,* that literally means “ Habitat Improvement Program”. This program a complex building program ran by 4 different agents:

➢ **BASE –A**

Figure 54. Base-A logo

Base-A is the coordinator and responsible of volunteer students who form the AWASUKA's technical team.

This association is a collective of university students and young people that understand the architecture as a tool of social transformation, where most of members are architects or architecture students, but there are also other individuals from the building trade.

Within the scope of cooperation and training, they perform activities in areas related to the construction, rehabilitation and urban planning from a viewpoint of sustainable and inclusive development.

➢ **AMICS DEL NEPAL**

Figure 55. Amics del Nepal logo

Amics del Nepal is the AWASUKA's general coordinator and who follow's up the economical themes.

This non-profit NGO (non-governmental development organization) is formed by volunteers whose main objective is the realization of cooperation projects and support programs for vulnerable groups of people, basically children, young people and women, both directly and in collaboration with Nepalese organizations.

Amics del Nepal also has the objective of disseminate the cultural and social reality of Nepal in our society, through the realization and organization of awareness activities.

➢ **UPC-CCD**

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Centre de Cooperació per al Desenvolupament

Figure 56. UPC-CCD logo

The UPC-CCD (*Centre de Cooperació per al Desenvolupament* from *Universitat Politècnica de Catalunya*) collaborates with AWASUKA offering an expert advisor on Habitat Improvement Programs through cooperatives (a university professor), and also grants an economical aid to the program financing volunteer's maintenance during their stays in Nepal.

The CCD is a unit of the UPC University created with the mission of promoting an active involvement of the UPC in cooperation projects for development, and supporting the realisation of initiatives in this field by whoever UPC member. It also assumes a training and awareness task of these type of problems.

As a fundamental part of its mission to serve society, the University has the responsibility to participate actively in the promotion of solidarity and equity between people and in promoting a better human and sustainable development in the world, based on it own university activities: teaching, researching and the transfer of knowledge and technology.

- **Agragaami Krishak Krishi Sahakari**

Figure 57. Agraami logo

Agricultural cooperative working with AWASUKA as local partner, who manages legal status and the social organisation with the local people.

The program's main objective is to strengthen the villagers and empower them with technical, social and economic expertise, so they can better respond to future earthquakes.

For doing it, from Barcelona engineers and architect worked on designing three prototypes of different constructive techniques for anti-seismic houses: with concrete block, with *dhunga-mato* (stone and mud) and with *patra* (local cheapest wood). Of these three prototypes, two are already finished and one (dhunga-mato) is almost finished.

Figure 58. Patra and block house finished

Figure 59. Dhunga-mato's prototype status at August of 2017

Once the three prototypes are completed, the villagers' houses will be rebuilt and AWASUKA will provide them with technical support, one work leader per home and a credit for materials. This enables the program to be sustainable economically, since the villagers will return the cost of materials and this money will be the basis for the revolving credit fund, which will make this program accessible to more people. The social organization is enhanced through various actions: doing social houses for very vulnerable families, fostering the "learning wheel" (beneficiaries who are apprentices in the first round of construction, can be teachers in the second round) and involving women to contribute in decision-making and knowledge transfer.

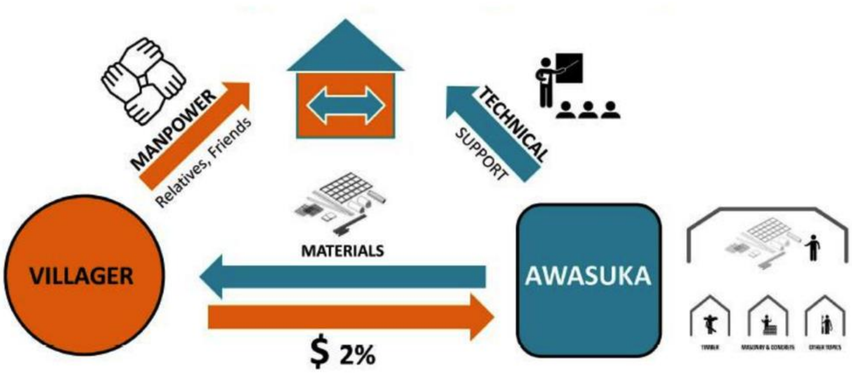


Figure 60. Sustainable working style of AWASUKA, by AWASUKA

This project wouldn't have been possible without the funders of the program. At September of 2017, there are the following:

Figure 61. Logos of the different funders of AWASUKA

9. GEOTECHNICAL STUDY

One of the tasks assigned from AWASUKA for the construction of new houses in Suping, Bhimphedi, has been to study the geotechnical properties of the soil in this new emplacement.

A geotechnical study previous to a building or infrastructure is considered indispensable for any construction in developed countries, but in the developing countries, even they know that provides them with important information, the truth is that for house construction they barely do. Therefore, this study has been server also to show the importance of it to local workers, at least in situ tests even, if they're not very precise.

This soil was identified at first sight as some kind of clay, but thanks to different soil tests, have been determined more characteristics and a more precise description.

9.1 SOIL TESTING

For this short geotechnical study, have been done different tests in Barcelona and in Nepal. For laboratory tests, it has been used 1 kg of soil provident from Niranjan's house[10] sent by AWASUKA volunteers, and extracted at a depth of 1m.

Tests can be classified in these two categories of purpose:

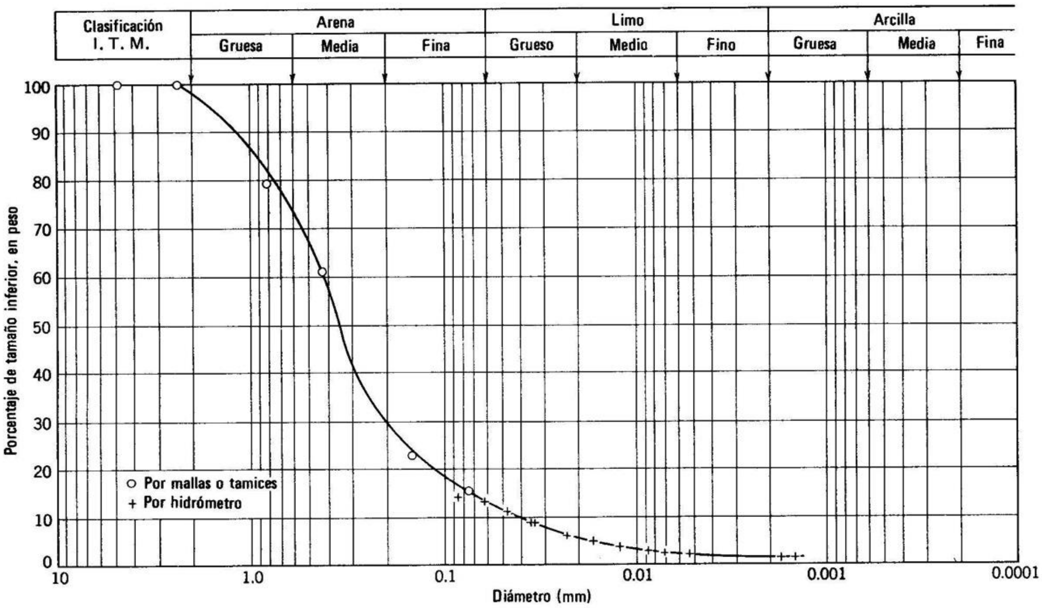
- Identifying tests
  - Grain Size Distribution
  - Casagrande Test (Liquid Limit)
  - Rolling Test (Plastic Limit)
- Resistance tests
  - Direct Shear Test (Shear Strength)
  - Table Load Test (Ultimate Bearing Capacity)

Has to be considered that it hadn't been possible to evaluate the soil behaviour at earthquakes (in situ) because all tests uses instruments not available in the area or adaptable to other rudimental devices, because most of these tests needed sensors, for example.

9.1.1 GRAIN SIZE DISTRIBUTION

The study of size distribution in a sample of soil is one of the most common and useful tests for grains that are going to be use in concrete. It is fundamental to be in a geotechnical study, because even if grains are not used for making concrete, it helps on identifying the type of soil and the proportions of gravel, sand and fines (clay + silt).

[10] Niranjan Pudassaine is one of the benefactors of a new house in Suping.



Graphic 1. Example of grading curve of a well-graded soil, by

The grain size analysis of a soil consists in determining the distribution by sizes of the particles that form it, by separating the aggregate into different fractions of particles of the same size or into sizes within certain limits. Once separated, for plotting the grading curve must be found the percentage of soil that contains every limit or size.

This study is made through a series of standardized sieves that can correspond to the series: international ISO, American Tyler or ASTM, British B.S. etc., or the Spanish UNE and seeing the amount that is retained in each of them. The sieves used for this test, as it was already predicted as a soil of fines, are the smaller ones:

A.S.T.M. SIEVES			
Coarse grains		*Fine grains*	
Designation	Grain diameter [mm]	Designation	Grain diameter [mm]
Nº 10	2		
Nº 16	1,18	Nº 16	1,18
Nº 40	0,425	Nº 40	0,425
Nº 100	0,15	Nº 100	0,15
Nº 200	0,075	Nº 200	0,075

Table 4. Sieves used for the test

It can be noted different sieves for coarse grains and for fines. The explanation to this is that, previously to prepare the grains washing them, the sample of soil passed through a sieve #10 to treat by separate clearly coarse grains from fines, and weight both subcategories.

$$m_{T,\ dry} = 230{,}27g$$

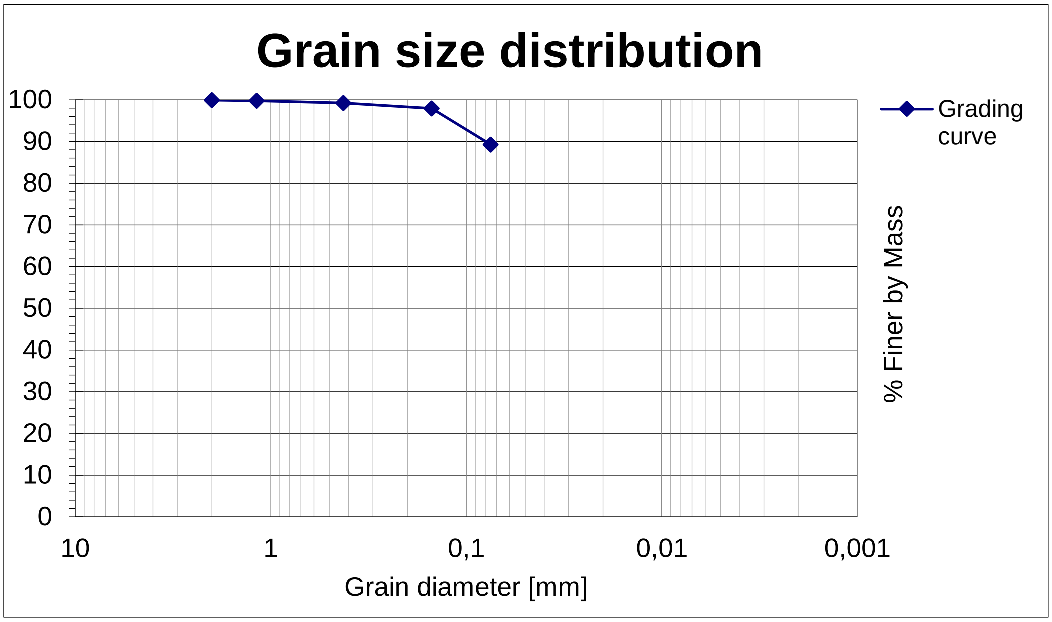
$$m_{retained\ \#10,\ dry} = 0{,}76\ g\ \rightarrow\ Coarse\ fraction$$

$$m_{passed\ \#10,\ dry} = 229{,}27\ g\ \rightarrow\ Fine\ fraction$$

Once passed through all sieves, the total distribution has been the following:

Sieve diameter [mm]	Soil passed
63	100 %
50	100 %
38,1	100 %
25	100 %
19	100 %
12,5	100 %
9,5	100 %
4,75	100 %
2	99,94 %
1,18	99,8 %
0,425	99,24 %
0,15	97,92 %
0,075	89,28 %
Fines	0

Table 5. Result of grain distribution in sieves



Graphic 2. Resultant grain size distribution

Analysing the resulting curve, the soil tested has a grain's size distribution that corresponds a uniform graduation, because the size of its grains pertain to the same grain size: fines. The proportions of each soil type are the followings:

% Gravel = 0,06 %

% Sand = 10,66 %

% Fines (Clay + Silt) = 89,28 %

CLAYEY OR SILTY SOIL

As the percentage of fines is more than a 50%, the soil is determined as fine, so as clay or silt. It had been possible also to posteriorly sediment the fines in order to exactly determine the proportions of clay and silt, but they're not indispensable or necessary in this test.

9.1.2 PARTICLE DENSITY

From the density of a soil, which can be defined as weight per unit of volume of the soil, can be distinguished two different densities: bulk density and particle density. The particle density is the weight per unit volume of the solid portion of a soil, meanwhile bulk density would be the dry weight of soil, including of pore spaces.

Thanks to the value of particle density, it is possible to identify the solid material in more proportion of soil. The test available to find this value consists on calculating the volume displaced when a soil is submerged in alcohol at a constant temperature, which was originally also constant at the same temperature, and later divide the difference of weight by the volume calculated.

The test is done with a pycnometer inside a tank of water with a dispositive to regulate the temperature of its water. It is very important to remove scrupulously the bubbles of air from the mix when the soil is added to the alcohol, and also to wait 5-6h each time is needed to stabilise the temperature on the water tank.

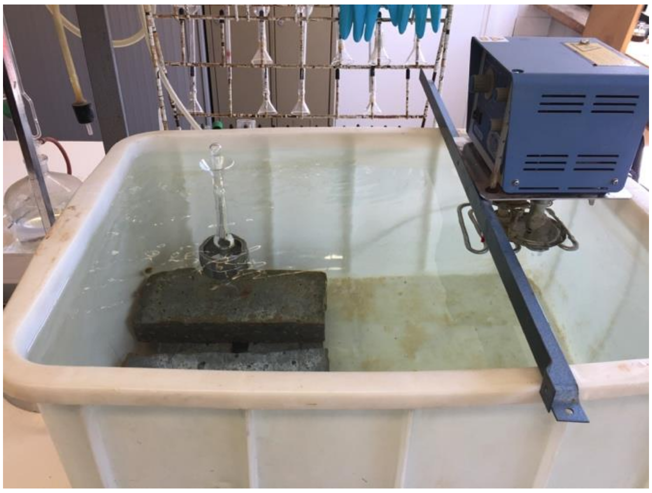



Figure 62. Proceed of the test

Values of alcohol at the beginning of the test, considering included in the volume the pycnometer and its cap, and the volume counted since the red line of the instrument:

$$m_{initial} = 355{,}42\ g$$

$$V_{initial} = 0{,}5\ mL$$

Values of alcohol and soil at the end of the test, considering included in the volume the pycnometer and its cap, and the volume counted since the red line of the instrument:

$$m_{final} = 410{,}66\ g$$

$$V_{final} = 20{,}9\ mL$$

The density of the solid particle of the soil is the following:

$$\rho_S = \frac{m_{final} - m_{initial}}{V_{final} - V_{initial}} = 2{,}7078\frac{g}{mL} = 2707{,}8\frac{kg}{m3}$$

9.1.3 ATTERBERG LIMITS

Atterberg limits or also called consistency limits are based on the concept that fine soils can be found in nature in different states, depending on their own nature and the amount of water that they contain. A soil can be found in solid, semi-solid, plastic or liquid or viscous state.

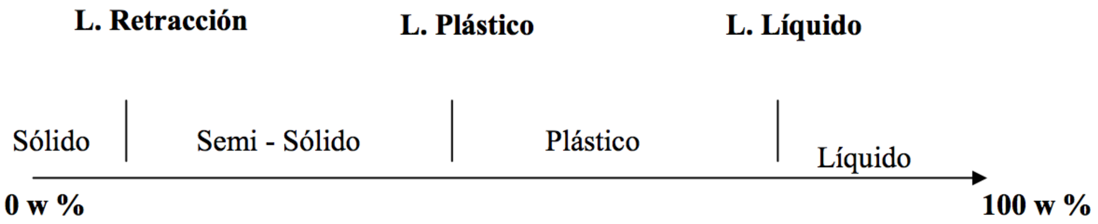


Figure 63. Soil's states diagram with Atterberg limits, by UPCommons

As it is seen in the diagram, Atterberg limits are the values of content of water that divides the different physical states of a soil. With these humidity values, it's going to be able to identify more accurately the soil type.

CLASIFICACIÓN DE SUELOS ASTM

DIVISIONES PRINCIPALES			DEL GRUPO	DENOMINACIÓN TIPICA			CRITERIOS DE CLASIFICACIÓN	
SUELOS DE GRANO GRUESO Más del 50% es retenido en el tamiz nº 200	GRAVAS * 50% o más de la fracción gruesa es retenida por el tamiz nº 4	GRAVAS LIMPIAS	GW	Gravas y mezclas grava-arena bien graduadas, con pocos finos o sin finos	Clasificación basada en el porcentaje de finos que pasan por el tamiz nº 200 (0,080 UNE)	Menos del 5%: GW, GP, SW, SP Más del 12%: GM, GC, SM, SC Del 5 al 12%:Casos intermedios que requieren el uso de doble símbolo	$Cu = \frac{D_{60}}{D_{10}} > 4$ $Cc = \frac{D_{30}^2}{D_{10} \cdot D_{60}}$ entre 1 y 3	
			GP	Gravas y mezclas grava-arena mal graduadas, con pocos finos o sin finos			Cuando no se cumplen simultáneamente las dos condiciones para GW	
		GRAVAS CON FINOS	GM	Gravas limosas, mezclas grava-arena-limo			Debajo de la línea A o IP < 4	Los casos intermedios requieren doble símbolo
			GC	Gravas arcillosas, mezclas grava-arena-arcilla			Por encima de la línea A o IP > 7	
	ARENAS Más del 50% de la fracción gruesa pasa por el tamiz nº 4	ARENAS LIMPIAS	SW	Arenas y arenas con grava bien graduadas, con pocos finos o sin finos			$Cu = \frac{D_{60}}{D_{10}} > 6$ $Cc = \frac{D_{30}^2}{D_{10} \cdot D_{60}}$ entre 1 y 3	
			SP	Arenas y arenas con grava mal graduadas, con pocos finos o sin finos			Cuando no se cumplen simultáneamente las dos condiciones para SW	
		ARENAS CON FINOS	SM	Arenas limosas, mezclas de arena y limo			Debajo de la línea A o IP < 4	Los casos intermedios requieren doble símbolo
			SC	Arenas arcillosas, mezclas de arena y arcilla			Por encima de la línea A o IP > 7	
SUELOS DE GRANO FINO 50% o más pasa por el tamiz nº 200	LIMOS Y ARCILLAS Límite líquido igual o menor que 50		ML	Limos inorgánicos, arenas muy finas, polvo de roca, arenas finas limosas o arcillosas				
			CL	Arcillas inorgánicas de plasticidad baja a media, arcillas con grava, arcillas arenosas, arcillas limosas				
			OL	Limos orgánicos y arcillas limosas orgánicas de baja plasticidad				
	LIMOS Y ARCILLAS Límite líquido mayor que 50		MH	Limos inorgánicos, arenas finas o limos con mica o diatomeas, limos elásticos				
			CH	Arcillas inorgánicas de elevada plasticidad				
			OH	Arcillas orgánicas de plasticidad media a elevada				
SUELOS DE ESTRUCTURA ORGÁNICA			PT	Turbas, fangos y otros suelos de alto contenido orgánico	Fácilmente identificables por la presencia de raíces, hojas y materia vegetal fibrosa en descomposición, así como su color marrón oscuro ó negro, su olor y su tacto suave y esponjoso			

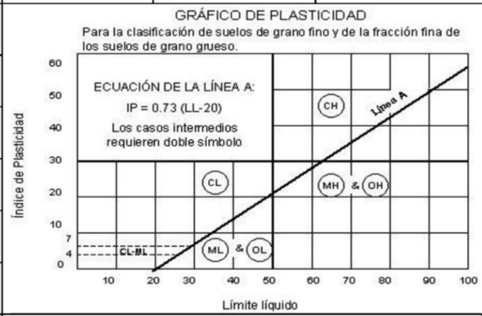


Figure 64. Soil Classification according to Atterberg limits, by ASTM

For this identifying task, the parameters needed are the following:

- *Liquid limit* (LL or ω_L): Water content in a sample since a liquid soil can turn into plastic state and vice versa. If the soil stays in a liquid state, it behaves as viscous fluid and flow under its own weight.
- *Plastic limit* (PL or ω_P): Water content in a sample since a plastic soil can turn into semi-solid state and vice versa. If the soil stays in a plastic state, it becomes deformed easily to whatever shape under a light pressure on it.
- *Plasticity index* (IP): Value that determines the magnitude of the range of water contents where the soil has a plastic behaviour.

$$PI = \omega_P - \omega_L$$

There is a specific test to determine each parameter. For the liquid limit has been used the Casagrande cup method and for the plastic limit, the rolling method; both are strictly defined by ASTM standard test method D 4318, and have been followed to the letter. Results for both methods have been the following:

Plastic limit by rolling test

This test consists on rolling out a thread of a sample of the soil over a flat and non-porous surface. The plastic limit is defined as the moisture content where the thread breaks apart at a diameter of 3.2 mm, so threads must be rolled perpendicular to length axis until a longitudinal crack appear.

Once there have been a considerable number of thread samples at the plastic moisture, they have been dried 24h at the oven. The results have been the following:

Tare Reference	Code C1
m_T	12,55 g
m_{T+S+W}	17,33 g
m_{T+S}	16,44 g
m_W	0,89 g
m_S	3,89 g
% ω	22,88 %

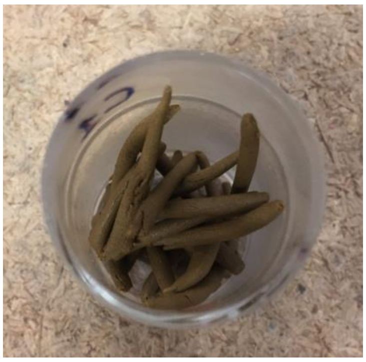


Figure 65. Resulting sample

Table 6. Results from rolling test

Where: T = Tare; S = Soil; W = Water

According to the results, the humidity from what a plastic will come into semi-solid state or vice versa, is at 23% of water content.

Liquid limit by Casagrande test

This test consists on determining at which water content a soil deposed at Casagrande's cup can close a groove in the middle in exactly 25 drops of the cup. Therefore, the proceed is to prove different water contents in the same sample (by just adding water little by little) and find by a linear regression of the results the approximated water content that closes the grove in 25 drops. To get it, every time a Casagrande''s test has finished, must be keept a 2-3g sample of soil with its specific moisture.

Figure 66. Proceed with Casagrande's cup at the laboratory

Once there have been 4-5 samples of different water content (inside a range of 12 drops to 40), they have been dried 24h at the oven. The results have been the following:

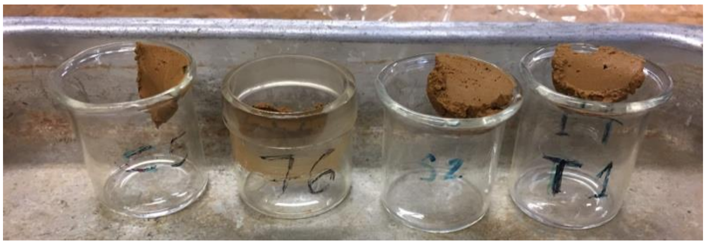


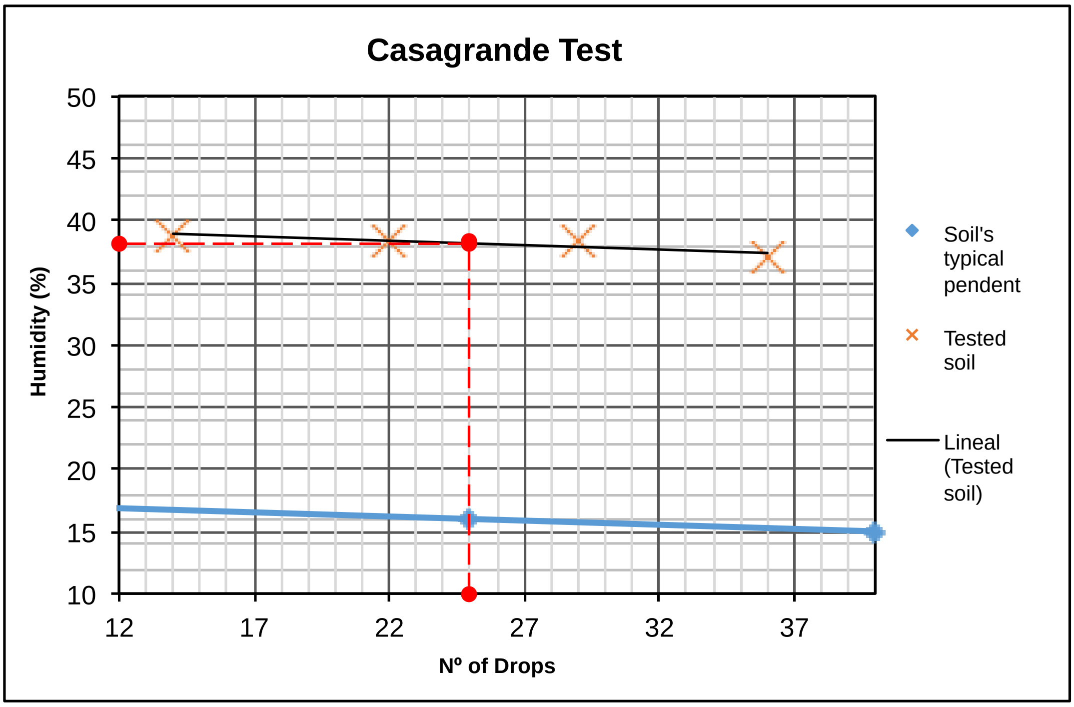
Figure 67. Resulting samples

Num of drops	43	36	29	22	14
Tare Reference	Code 76	Code S2	Code T1	Code C1	Code 76'
m_T	14,91 g	12,10 g	12,55 g	12,57 g	14,91 g
m_{T+S+W}	17,10 g	14,84 g	15,00 g	14,66 g	18,17 g
m_{T+S}	16,53 g	14,10 g	14,32 g	14,08 g	17,26 g
m_W	0,57 g	0,74 g	0,68 g	0,58 g	0,91 g

m_S	1,62 g	2,00 g	1,77 g	1,51 g	2,35 g
$\% \, \omega$	35,18%	37,00 %	38,42 %	38,41 %	38,72 %

Table 7. Results from Casagrande test

Where: T = Tare; S = Soil; W = Water



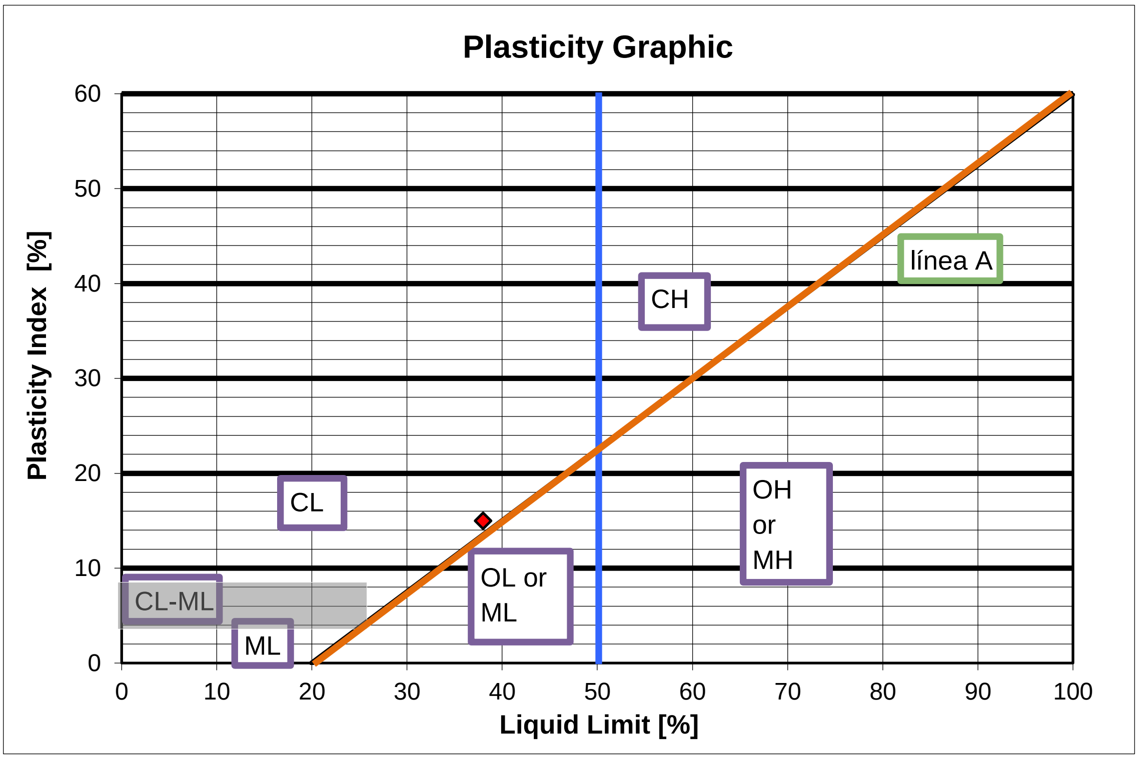
Graphic 3. Resultant flow pendant of Casagrande's test

$\omega_L = 38\%$

According to the results, the humidity from what a plastic will come into liquid state or vice versa, is at 38% of water content.

Once both tests have been solved and it have been found liquid and plastic limit, the plasticity index can be calculated and plotted into plasticity graphic:

$$PI = \omega_P - \omega_L = 38 - 21 = 15\%$$



Graphic 4. Plasticity graphic from ASTM with soil plotted in red

As it is seen in the plasticity graphic, concurring with ASTM classification the soil tested is categorised as CL, which literally means:

Inorganic clay from low plasticity to medium, clay with gravel, sandy clay or silty clay

Therefore, regarding that the soil is clearly determined as a type of clay, thanks to the liquid limit and the plastic limit it is possible to detect which clay minerals may contain the soil.

Mineral[a]	Límite líquido (%)	Límite (%
Montmorillonita (1)	100-900	50-
Nontronita (1)(2)	37-72	19-
Illita (3)	60-120	35-
Caolinita (3)	30-110	25-
Halosyta hidratada (1)	50-70	47-
Halosyta deshidratada (3)	35-55	30-

Table 8. Atterberg limits for clay minerals, by J.K.Mitchel

Agreeing to this table, one of possible minerals in the soil would be Nontronite.

9.1.4 SHEAR STRENGHT

Direct Shear Test

The purpose of shear tests it's to determine the resistance of a soil's sample under fatigue and/or deformations, simulating the real ones that will suffer in field because of a load application.

The shear strength equation was first proposed by the famous French engineer Coulomb. He expressed the shear strength as a linear function of total normal stress on the potential surface of sliding. His equation was the following:

$$\tau = c + \sigma \tan \phi$$

Where:

- τ = Shear stress
- σ = Normal stress
- ϕ = Friction angle[11]
- c = Cohesion[12]

To obtain this equation in a laboratory, the easiest method to obtain the components is applying the direct shear test. It consists in a circular or square based box divided horizontally in two same halves where, inside of it, it's placed a sample of the soil wanted to calculate, and also two porous stones in both external sides. Over this box, it is applied a vertical confining load fixed in time, and later an horizontal increasing load will be applied to the lower half of the box, causing a differential and opposite displacement in between both halves.

[11] Due to interlocking of soil particles and the interaction between them.

[12] Due to mutual attraction that exists between the fine particles of some soils.

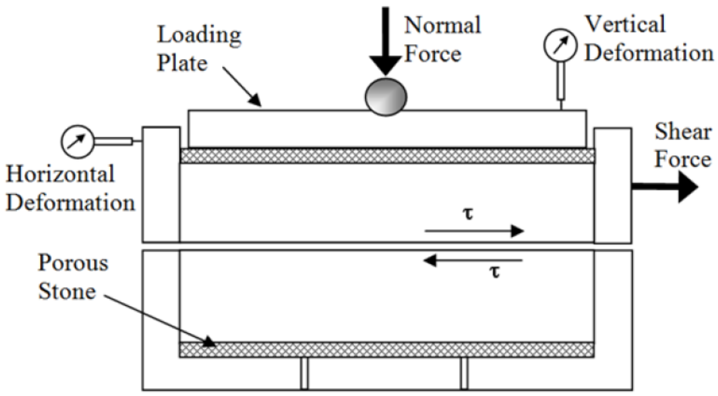
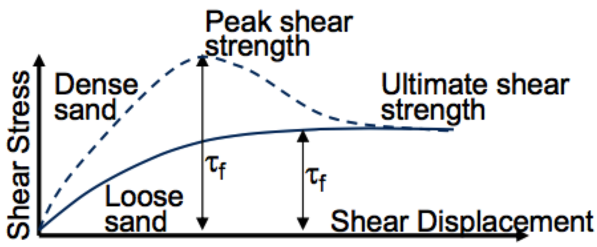


Figure 68. Schema of direct shear test box, by IIT Gandhinagar

As it is seen in the representation, this test induces a fault plane because two different stresses: a normal stress (σ_n) caused by a vertical load and a shear stress (τ) caused by the progressive horizontal load, and both forces will origin deformations in both directions.

Considering a minimum number of two tests at different normal stresses, with the different measurements of shear deformations at every horizontal load value it is possible to obtain the Shear stress-strain curve for each normal stress.



Graphic 5. Elements of shear stress-displacement curve of a sandy soil, by Widener University

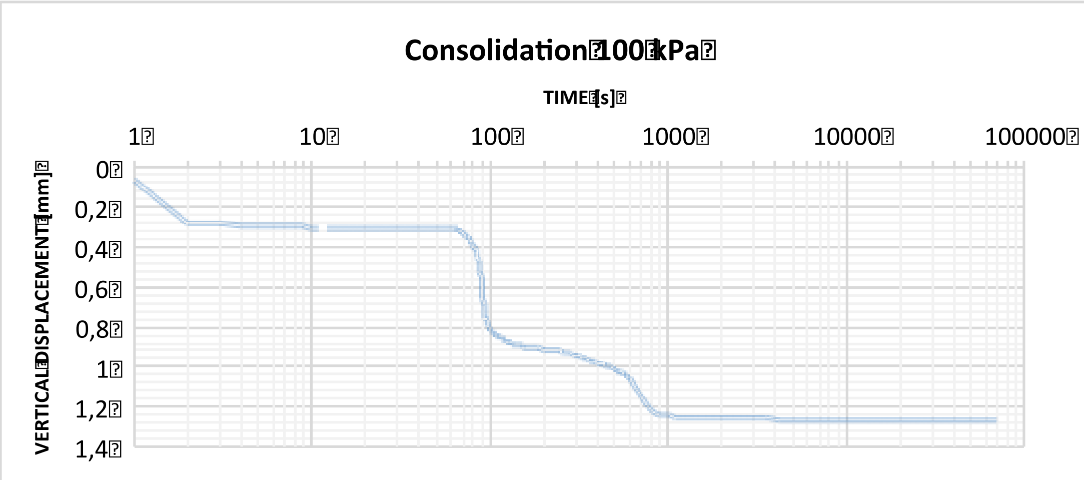
In direct shear test, there are two different classifications that determine the test's procedure. In this test, the categories chosen have been the following:

- According to drainage and/or consolidation in the soil sample
  - Drained consolidated test (CD): Slow speed of test that allows drainage on the soil sample during the whole test, being nulls interesticial pressure during shear stress. It imply the following changes: σ = σ', c = c', Φ = Φ'.
- According to applying technique adopted with the horizontal stress:

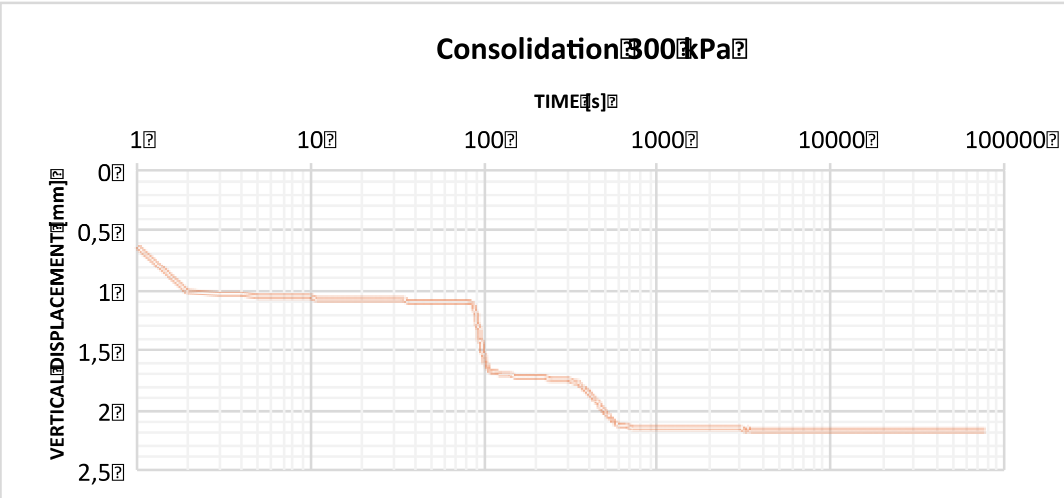
- Strain controlled: The lower half of box displaces at a constant speed, and horizontal stresses are measured by a dynamometric ring connected to the horizontal load.

With the limited soil available as sample from the emplacement, it has only been possible to do two direct shear tests (the minimum told): one with a vertical stress of 100 kPa and another with 300 kPa. Considering separately both stresses, the resulting shear strength curves have been the following:

Consolidation phase:



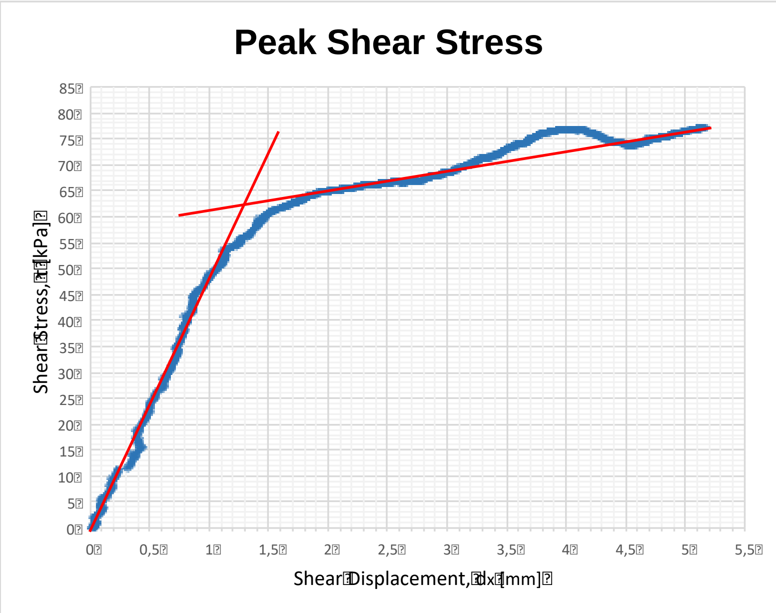
Graphic 6. Vertical displacement in time, at load 100 kPa



Graphic 7. Vertical displacement in time, at load 300 kPa

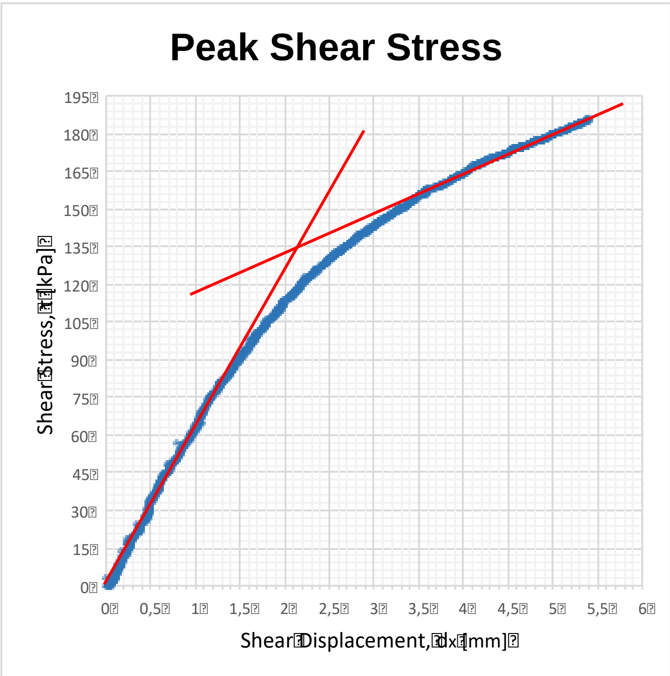
Shear phase:

$$Shear\ stress\ (\tau) = \frac{Load\ (m) \cdot Gravity\ (g)}{Application\ area\ (A)}$$



Peak Shear Stress = 62 kPa

Graphic 8. Shear strength curve at 100 kPa of normal stress

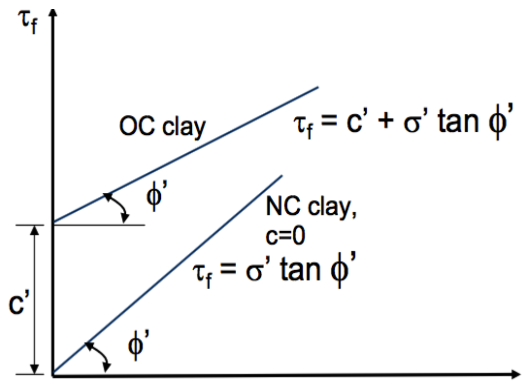


Peak Shear Stress = 135 kPa

Graphic 9. Shear strength curve at 300 kPa of normal stress

Both curves don't present a clear peak on them, so in these cases there are two possibilities of determining the shear peak stress: considering a fixed displacement for both tests, take the shear stress value; or, with the ascendant curve obtained, evaluate the two different pendants and take the stress value of the point where they collide. In these test, the method considered has been the second one.

Once found the shear strength (or shear stress peak) for both normal stresses, it is possible to represent the resulting straight line. This line is the called failure envelope[13] of a soil; it represents graphically all failure status with a shear and normal stress given.



Graphic 10. Elements of the failure envelope of an OC[14] clay and NC clay[15], by Widener University

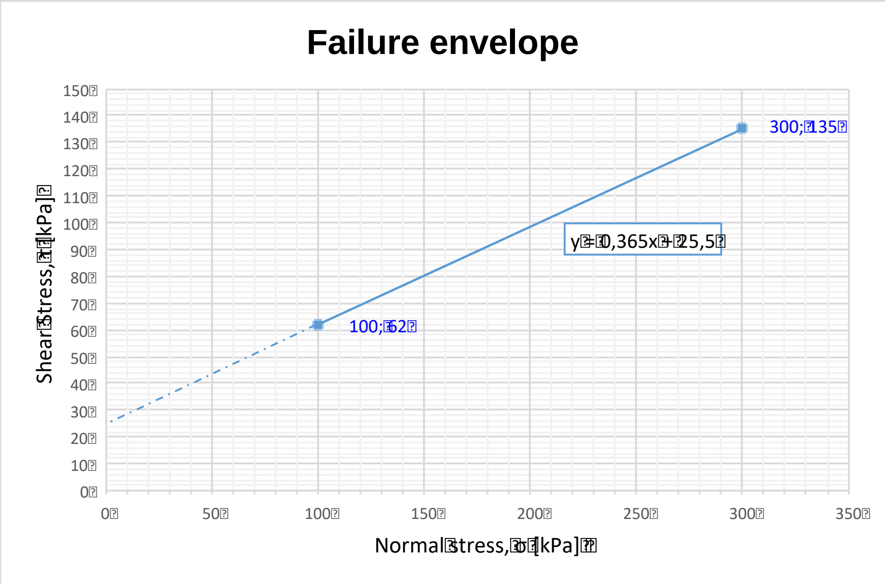
In consequence, once represented the failure envelope, it is also possible to determine graphically other soil parameters such as its cohesion and friction angle. And with al this items, obtain the shear strength equation from Coulomb characteristic for this soil.

	Shear Stress (kPa)	Normal Stress (kPa)
Test 1	62	100
Test 2	135	300

[13] According to Coulomb. Not to confuse with Mohr's failure envelope.

[14] Over Consolidated

[15] Non-Consolidated



Cohesion
25,5 kPa

Friction angle
20,052 °

Graphic 11. Failure envelope from direct shear test

As a result, it's concluded that the clay is considerate over-consolidated and that Coulomb's shear strength equation is the following:

$$\boldsymbol{\tau = 25,5 + \sigma \tan(20,052°)}$$

Has to be considered that the direct shear test has the following limitations or handicaps:

- The sample area during the shear changes while the test proceeds and in the graphic obtained it has been supposed as constant. This area could have been corrected, but not doing it stays on the side of safety.
- Shear surface is supposed to be flat and the shear stress distributed uniformly along this surface, but this supposition is not always correct.
- As the sample taken is very small, mistakes in the preparation can become very significant.

9.1.5 BEARING CAPACITY

Load Table Test

The load table test is a simplification of the standardized Plate load test, that is applicable when the required instruments for the test are not available in the emplacement or area, whichever reason why.

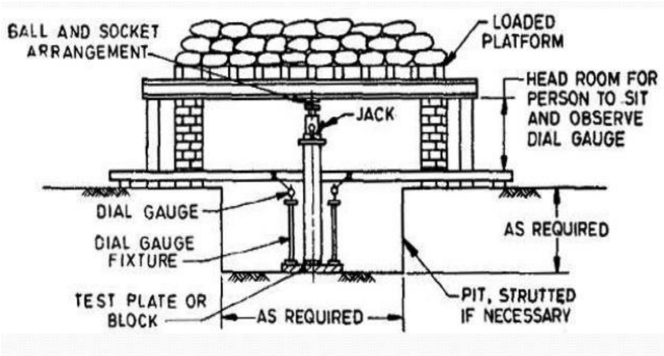


Figure 69. Plate load test schema, by The Construction Civil

As the plate load test, it is a field test for determining the ultimate bearing capacity of soil and the likely settlement under a given load. It basically consists of loading a wooden robust table placed at the foundation level, where the load is gradually increased till the table settles between 3 to 5 mm. At that moment, the acting load becomes the ultimate load value and, if gets divided by the area of appliance, it gives the value of the ultimate bearing capacity of soil.

This soil test was made at foundation level of Niranjan's house of new construction on August of 2017 so, in consequence, in monsoon season.

It was used a table self-made with the local cheapest wood, and it measures were 10x10x70 cm each leg and 61x61x1.5 cm the table-top. As load, they were used stones and mud from the emplacement and even a person's weight, applied all on the board in cumulative series of 50kg.

$$Equivalent\ area\ (A_{eq}) = 4 \cdot (10cm \cdot 10cm) = 400\ cm^2$$

In the test, every round of 50kg took 30 minutes once applied to rest and settle on the ground. It was not until the load applied was 250 kg that the table settled for 3-4 mm. According to the theory explained, between this load and the previous 50kg batch (200kg of load) is found the ultimate bearing capacity of the soil.

$$Ultimate\ load\ (m_u) = 200 - 250\ kg$$

$$q_u^1 = \frac{m_u}{A_{eq}} = \frac{200\ kg}{400\ cm^2} = 0{,}5\frac{kg}{cm^2} = 49{,}033\frac{kN}{m^2}$$

$$q_u^2 = \frac{m_u}{A_{eq}} = \frac{250\ kg}{400\ cm^2} = 0{,}625\frac{kg}{cm^2} = 61{,}29\frac{kN}{m^2}$$

$$\boldsymbol{q_u = 49,03\ to\ 61,29\ kPa}$$

Tabla 8.1
Presiones admisibles en el terreno de cimentación

Naturaleza del terreno	Presión admisible en kg/cm², para profundidad de cimentación en m de:				
	0	0,5	1	2	≤ 3
1 Rocas (1)					
No estratificadas	30	40	50	60	60
Estratificados	10	12	16	20	20
2 Terrenos sin cohesión (2)					
Graveras	—	4	5	6,3	8
Arenosos gruesos	—	2,5	3,2	4	5
Arenosos finos	—	1,6	2	2,5	3,2
3 Terrenos coherentes					
Arcillosos duros	—	—	4	4	4
Arcillosos semiduros	—	—	2	2	2
Arcillosos blandos	—	—	1	1	1
Arcillosos fluidos	—	—	0,5	0,5	0,5
4 Terrenos deficientes	En general resistencia nula, salvo que se determine experimentalmente el valor admisible.				
Fangos					
Terrenos orgánicos					
Rellenos sin consolidar					

Observaciones:

(1) a) Los valores que se indican corresponden a rocas sanas, pudiendo tener alguna grieta.
b) Para rocas meteorizadas o muy agrietadas las tensiones se reducirán prudencialmente.

(2) a) Los valores indicados se refieren a terrenos consolidados que requieren el uso del pico para removerlos.
Para terrenos de consolidación media en que la pala penetra con dificultad, los valores anteriores se multiplicarán por 0,8.
Para terrenos sueltos, que se remuevan fácilmente con la pala, los valores indicados se multiplicarán por 0,5.
b) Los valores indicados corresponden a una anchura de cimiento igual o superior a 1 m. En caso de anchuras inferiores, la presión se multiplicará por la anchura del cimiento expresada en metros.
c) Cuando el nivel freático diste de la superficie de apoyo menos de su anchura, los valores de la Tabla se multiplicarán por 0,8.

Figure 70 **Admissible pressure in different foundation level, by AE-88**

Regarding the last table from AE-88, at a depth foundation of 1 meter, a bearing capacity of the soil studied corresponds a soft clayey soil, at least during monsoon conditions.

This test has some limitations or handicaps on its results, mostly because it was done in monsoon season. They are the followings:

- The soil must be at normal conditions to obtain the accurate results of its behaviour, and it was partially saturated because of monsoon.
- The realisation of the test is not compatible with rain, and in monsoon season rains everyday in this area. Mostly it starts on evening time, but in the case of this emplacement (because of its high sea level), starts raining at midday. So, as it took a lot of hours to do the test, the rain got the power to stop the test every at midday when started raining.
- As every round of load has a short duration, does not give the ultimate settlements, particularly in case of cohesive soils.

9.2 RESULTS

The results of this geotechnical tests, are compiled, resumed and interpreted into the following chart:

AUGUST OF 2017		**NIRANJAN PUDASSAINE HOUSE**
Presumed soil	Clay	
Propriety	**Value**	**Description / Interpretation**
Specific weight	1700 kg/m^3	Medium Clay. [4]
Particle density	2707,8 kg/m^3	Clay, Silty Clay, Sandy Clay or Silt. [6]
Liquid Limit	38%	-
Plastic Limit	23%	-
Plasticity Index	15%	As the soil has between 7 to 15% of plasticity (both included), the soil is considered as having Medium Plasticity.
	CL	Soil impermeable with regular to deficient shear strength and medium compressibility in compact state, and good/regular workability. [1]
		Dilatancia insignificant or very low, medium tenacity and medium to high strength to disaggregation. [3]
Cohesion	25,5 KPa	Medium Clay. [5]
Friction Angle	20º	Clay. [8]

Safe Bearing Capacity	50-60 kN/m^2	Soft Clay. [4] [10]
Ultimate Bearing Capacity	≈ 100 kN/m^2	Medium Clay. [4] [9]
Effect on ground response	The amplification of ground motion is moderated, the length of the predominant frequency is almost insignificant and the reduction of bearing capacity is small or insignificant. [2]	
S-wave velocity	390-410 m/s	Saturated Clay to Dry. [7]
P-wave velocity	200-2200 m/s	Dry Clay to Saturated. [7]
Soil type	**Over-consolidated soft to firm clayey soil with medium plasticity**	

Table 9. Results of geotechnical study

[1]

Denominaciones tipicas de los de los grupos de suelos.	Simbolo del grupo	PROPIEDADES MAS IMPORTANTES			
		Permeabilidad en estado compactado	Resistencia al corte en estado compacto y saturado excelente	Compresibilidad en estado compacto y saturado.	Facilidad de tratamiento en obra.
Gravas bien graduadas,mezclas de grava y arenas con pocos finos o sin ellos.	G W	Permeable	Excelente	Despresiable	Excelente
Gravas mal graduadas,mezclas de arena y grava con pocos finos o sin ellos.	G P	Muy permeable	Buena	Despresiable	Buena
Gravas limosas mal graduadas mezclas de gravas,arena y limo.	G M	Semipermeable a impermeable.	Buena	Despresiable	Buena
Gravas arcillosas, mezclas mal graduadas de gravas,arena y arcilla.	G S	Impermeable	Buena a regular	Muy baja	Buena
Arenas bien graduadas, arenas con grava con pocos finos o sin ellos.	S W	Permeable	Excelente	Despreciable	Excelente
Arenas mal graduadas, arenas con grava con pocos finos o sin ellos.	S P	Permeable	Buena	Muy baja	Regular
Arenas limosas,mezclas de arena y limo mal graduadas.	S M	Semipermeable a impermeable.	Buena	Baja	Regular
Arenas arcillosas,mezclas de arena y arcilla mal graduadas.	SC	Impermeable	Buena a regular	Baja	Buena
Limos inorgánicos y arenas muy finas polvo de roca, arenas finas arcillosas o limosas con ligera plasticidad	ML	Semipermeable a impermeable.	Regular	Media	Regular
Arcillas inorgánicas de baja a media plasticidad, arcillas con grava, arcillas arenosas, arcillas limosas, arcillas magras	CL	Impermeable	Regular	Media	Buena a Regular
Limos orgánicos y arcillas limosas orgánicas de baja plasticidad.	OL	Semipermeable a impermeable.	Deficiente	Media	Regular
Limos inorgánicos, suelos finos arenosos o limosos con mica o diatomeas, limos elásticos	MH	Semipermeable a impermeable.	Regular a deficiente	elevada	Deficiente
Arcillas inorgánicas de elevada plasticidad, arcillas grasas	CH	Impermeable	Deficiente	elevada	Deficiente
Arcillas orgánicas de plasticidad media a alta	OH	Impermeable	Deficiente	elevada	Deficiente
Turba y otros suelos inorgánicos	Pt	-	-	-	-

Table 10. Values by Catholic University of Valparaiso

TYPES OF SOIL			
NON PLASTIC PI = 0	LOW PLASTICITY PI = LOW	MEDIUM PLASTIC PI = MEDIUM	HIGHLY PLASTIC PI = HIGH
SANDS AND NONPLASTIC SILTS	SILTY CLAYS, CLAYEY SILTS, LOW PLASTICITY CLAYS	MEDIUM PLASTIC CLAYS	HIGH PLASTICITY CLAYS
EFFECT ON GROUND RESPONSE			
AMPLIFICATION OF GROUND MOTION			
INSIGNIFICANT OR NONE (ATTENUATION POSSIBLE)	SMALL, INSIGNIFICANT, OR NONE (ATTENUATION POSSIBLE)	MODERATE	LARGE
LENGTHENING OF PREDOMINANT PERIOD			
SIGNIFICANT DURING LIQUEFACTION PROCESS	LIKELY IF LARGER PORE PRESSURES BUILD UP	UNLIKELY OR INSIGNIFICANT	UNLIKELY OR IMPOSSIBLE
DEGRADATION OF STIFFNESS AND STRENGTH; REDUCTION OF BEARING CAPACITY			
LARGE, OR COMPLETE DURING FULL LIQUEFACTION	SIGNIFICANT FOR NORMALLY CONSOLIDATED OR SMALL OCR SOILS	SMALL, OR INSIGNIFICANT FOR OVERCONSOLIDATED SOILS	INSIGNIFICANT

[2]

Table 11. Values by C. V. R. Murty

		Métodos de identificación para la fracción que pasa por el tamiz Nº 40			
		Resistencia en estado seco (a la disgregación	Dilatancia (reacción a la agitación)	Tenacidad (consistencia cerca del límite plástico)	
Suelos de grano fino. Mas de la mitad del material pasa por el tamiz nº 200	Limos y arcillas límite líquido menor de 50	Nula a ligera	Rápida a lenta	Nula	ML
		Media a alta	Nula a muy lenta	Media	CL
		Ligera a media	Lenta	Ligera	OL
	Limos y arcillas límite líquido mayor de 50	ligera a media	Lenta a nula	Ligera a media	MH
		Alta a muy alta	Nula	Alta	CH
		Media a alta	Nula a muy lenta	Ligera a media	OH
Suelos altamente orgánicos		Fácilmente identificables por su color, olor, sensación esponjosa y frecuentemente por su textura fibrosa			Pt

[3]

Table 12. Values by Google

Peso específico γ y capacidad portante σ_{adm}

CLASE DE SUELO	PESO ESPECIFICO γ (Kg/m³)	CAPACIDAD PORTANTE σ_{adm} (Kg/cm²) Suelo seco	Suelo inundado	OBS.
Roca dura, estratificada, sana y compacta	2.800 a 3.000	60 a 100	-	(1)
Roca no estratificada, con algunas fisuras	2.700	40 a 50	-	(1)
Rocas estratificadas	2.600	25 a 30	-	(1)
Piedra caliza compacta	2.500	10 a 20	-	
Piedra caliza porosa	2.000	8 a 10	-	
Esquistos o roca blanda	1.800 a 2.000	8	-	
Grava con arena compacta (al menos 1/3 de grava de 70 mm)	2.000	5 a 8	2 a 4	
Arena gruesa firme y con algo de humedad (1 a 3 mm)	1.900 a 2.000	4 a 6	2	(2)
Arena gruesa seca	1.800	3 a 5	-	(2)
Arena fina húmeda	1.750	2 a 5	1 a 2	(2)
Arena fina seca	1.700	1 a 2	-	(2)
Arena arcillosa mediana y densa	1.900	2 a 3	0.5 a 1	
Arena arcillosa seca y suelta	1.700	1 a 2	-	
Arcilla dura compacta	1.800	4	-	
Arcilla muy firme	1.800	2 a 3	-	
Arcilla semidura	1.750	1 a 2	-	
Arcilla mediana	1.700	0.5 a 1	-	
Arcilla blanda	1.700	<0.5	-	
Limos	1.700	<0.4	-	
Fango, lodo o turba inorgánica	900	-	-	(3)
Suelos orgánicos	1.600	-	-	(3)
Tierra vegetal seca	1.700	-	-	(3)
Rellenos sin consolidar	1.700	-	-	(3)

[4]

Table 13. Values by Santiago de Chile University

TABLA A-3

Valores de la conesión c en suelos arcillosos

CLASE DE SUELO	c (Kg/cm²)
Arcilla muy blanda	-
Arcilla Blanda	0.05 a 0.10
Arcilla mediana	0.25 a 0.50
Arcilla firme	0.60 a 0.80
Arcilla muy firme	0.80 a 1
Arcilla dura y compacta	1 a 1.2
Arcilla arenosa densa	0.40 a 0.60
Arcilla arenosa suelta	0.10
Limo	0.10 a 0.30

[5]

Table 14. Values by Santiago de Chile University

Tipo de suelo	Densidad de sólidos Gs
Grava	2.65
Arena media a gruesa	2.65
Arena fina limosa	2.65
Loess, polvo de roca y limo-arenoso	2.67
Arena arcillosa	2.65
Limo arenoso	2.66
Limo	2.67-2.70
Limo arcilloso	2.68
Arena-limo-arcilla	2.69
Limo arcilla	2.71
Arcilla arenosa	2.70
Arcilla limosa	2.75
Arcilla	2.72-2.80
Limo con materia orgánica	2.30
Arcilla aluvial orgánica	2.13-2.60
Turba	1.50-2.15

[6]

S-wave velocity	
Clay (dry)	410 m/sec
Clay (saturated)	390 m/sec
Alluvium	1900 m/sec
Water	0 m/sec (because no shear strength)
Oil	0 m/sec (because no shear strength)
Air	0 m/sec (because no shear strength)
Limestone	3100 m/sec
Sandstone	2400 m/sec
Dolomite	3000 m/sec
Shale	2600 m/sec
Granite	3400-3600 m/sec
Dolerite	3500-3600 m/sec
Salt	2700 m/sec

P-wave velocity	
Soil	100-500 m/sec
Glacier ice	3000-4000 m/sec
Clay (dry)	200-1400 m/sec
Clay (wet)	1200-2200 m/sec
Alluvium	3000-5000 m/sec
Water	1450-1500 m/sec
Sand	400-2300 m/sec
Oil	1300 m/sec
Air	320-340 m/sec
Granite	3000-5900 m/sec
Basalt	4500-6500 m/sec

[7]

Table 15. Values by Texas University At Austin

Angle of internal friction (ϕ)	
Rock	30°
Sand	30-40°
Gravel	35°
Silt	34°
Clay	20°
Loose sand	30-35°
Medium sand	40°
Dense sand	35-45°
Gravel with some sand	34-48°
Silt	26-35°

[8]

Table 16. Angle of internal friction, by Texas University At Austin

S. No.	Soil consistency	q_u (kg/cm^2)
1.	Very soft	0–0.25
2.	Soft	0.25–0.5
3.	Medium	0.5–1.0
4.	Stiff	1.0–2.0
5.	Very stiff	2.0–4.0
6.	Hard	> 4.0

[9]

Table 17. Soil consistency, by Z.Khan

Table 9.1. Safe bearing capacity of different types of soil

S. No.	Type of soils	Safe bearing capacity	
		in t/m^2	in KN/m^2
	(A) Cohesionless soils		
1.	Gravel, sand and gravel, compact and offering high resistance to penetration when execrated by tools (see note 2).	44.0	440
2.	Coarse sand, compact and dry (see note 3)	44.0	440
3.	Medium sand, compact and dry	24.5	245
4.	Fine sand, silt (dry lumps easily pulverized by the fingers)	15.0	150
5.	Loose gravel or sand gravel mixture, loose coarse to medium sand, dry (see note 2).	24.5	245
6.	Fine sand, loose and dry	10.0	100
	(B) Cohesive soils		
7.	Soft shale, hand or stiff clay in deep bed, dry	44.0	440
8.	Medium clay, readily indented with a thumb nail	24.5	245
9.	Moist clay and sand clay mixture which can be indented with strong thumb pressure	15.0	150
10.	Soft clay indented with moderate thumb pressure	10.0	100
11.	Very soft clay which can be penetrated several centimetres with the thumb	5.0	50
12.	Black cotton soil or other shrinkable or expansive clay in dry condition (50% saturation).	To be determined after investigation (see note 4)	
	(C) Peat		
13.	Peat	–do– (see notes 4 and 5)	
	(D) Made up ground		
14.	Fills or made up ground	–do– (see notes 2 and 5)	

[10]

Table 18. Safe bearing capacity of different soil, by National Building Code of India

10. FOUNDATION'S PROJECT

Once the geotechnical study has been concluded and the soil type and properties have been identifyied, the second step is to finally design the foundation system for the new Suping houses.

A foundation project consists on different consecutive phases, not just the design one. With the all soil data provided in the geotechnical study, have to be considered all Nepali limimtations for a design; this includes specific regulations for constructing any building in Nepal (resumed in NBC[16]) but also different agents to be considered because of this specific construction (as the construction style, for example).

[16] Nepal National Building Code (NBC)

When all this information is compiled and analysed, then the foundation design can start properly; and, after whatever time needed, the construction would be ready to start.

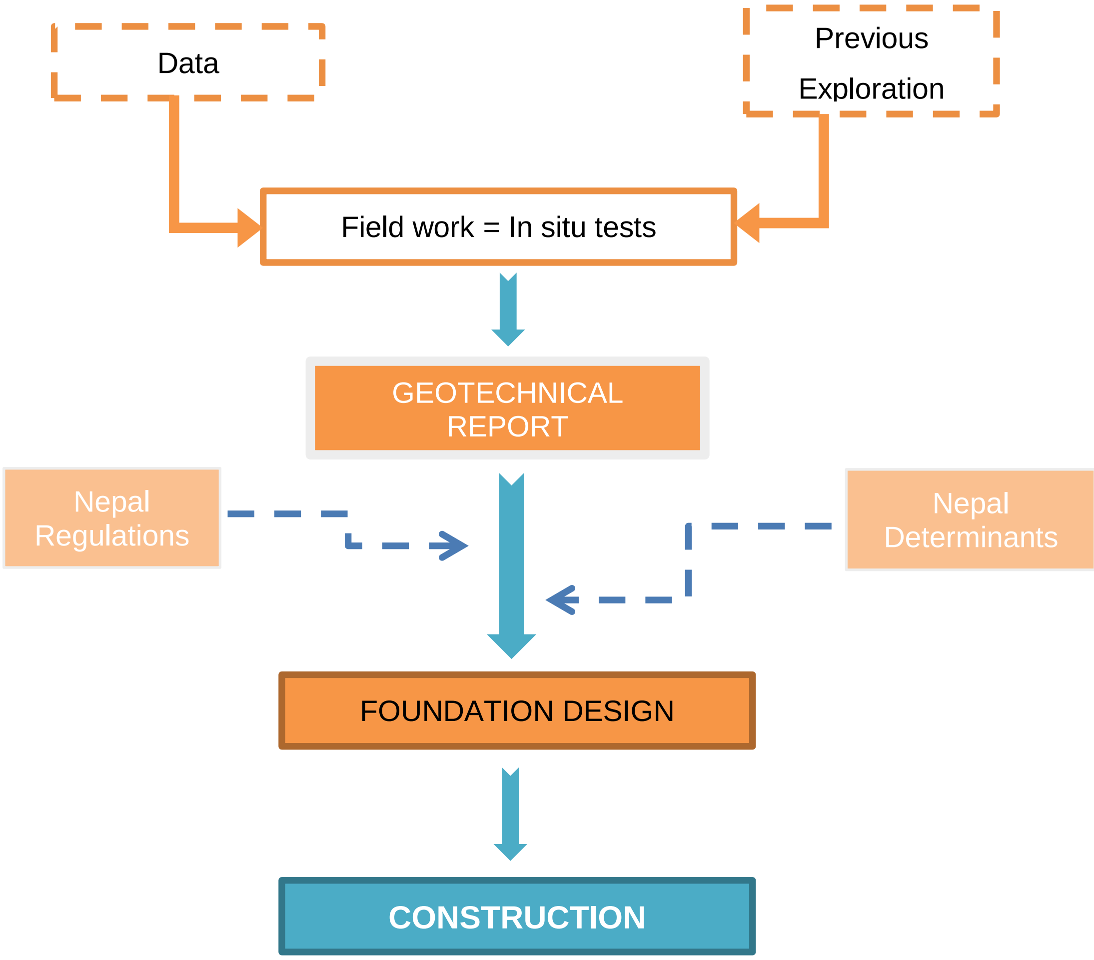


Figure 71. Diagram of a foundation project

In this practical case, it will be defined a range of possible options of foundation adapted to different simple characteristics, because not all 7 new houses have the same reality in all aspects.

10.1 DETERMINANT AGENTS

For a specific construction, couple of agents determine the design and construction of the building. In the new 7 houses that are going to be construct in Suping ward, influential agents can be grouped in the following categories:

- **Because of the country**

Being Nepal the country of the emplacement is a really significant and limiting agent to consider. As it has been explained previously, is considered in the list of least developed countries at the moment, and this aspect supposes two considerable limitations:

- *Low budget:* At exception of few ones, most of Nepali people live in austerity and with a really low budget for daily lives. This is proportional also to their budgets to build new houses, so the amount of material and of workers must be as low as possible. And houses, as simple as possible.
- *Limited Building Technologies:* In developed countries, many machines and sophisticated proceeds are used daily to build houses. In Nepal, construction processes still use rudimental methodologies and tools, so the design must be thought to be construct very easy and with basic tools or machines.

Besides of Nepal's problem with its development, its geographical situation also affects to the construction, mainly because its hazard to natural disasters. Houses have to be specially prepared for two risks:

- *Floods:* Nepal, as other South Asian countries, has a wet season in its calendar. This season is called Monsoon and it causes daily rains in all the country, so houses have to be prepared for a dose of rain everyday during 2 to 3 months. These quotidian rains will be mostly light, but some days in the season will rain heavily without doubt. Because of it, Nepal is an area where commonly there are floods every year, and afterwards, houses need to be prepared for it.
- *Earthquakes:* As it has been said in previous sections, Nepal is over a tectonic plate border, exactly where Indian and Eurasian collide (and

forms the Himalayan range). Therefore, new houses must be as resistant as possible against earthquake damages.

- **Because of its emplacement**

The emplacement for the new houses designed, Suping ward, is the 9th ward of Bhimphedi, situated at 1600m from sea level as average, noticeably higher than Bhimphedi that it's at 1115m.

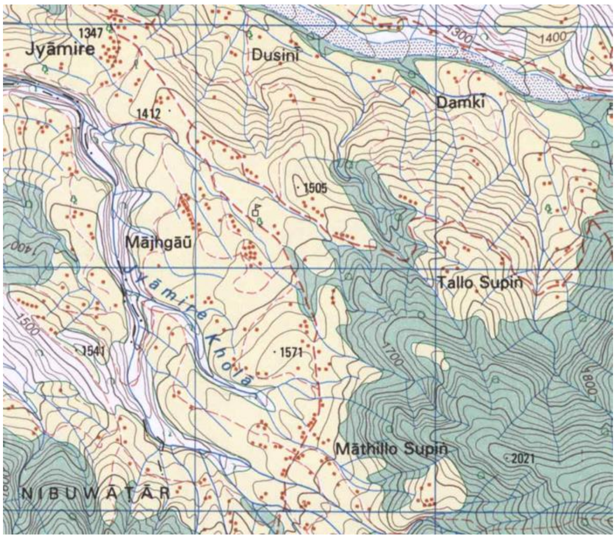


Figure 72. Map of Suping Area, by the Government of Nepal

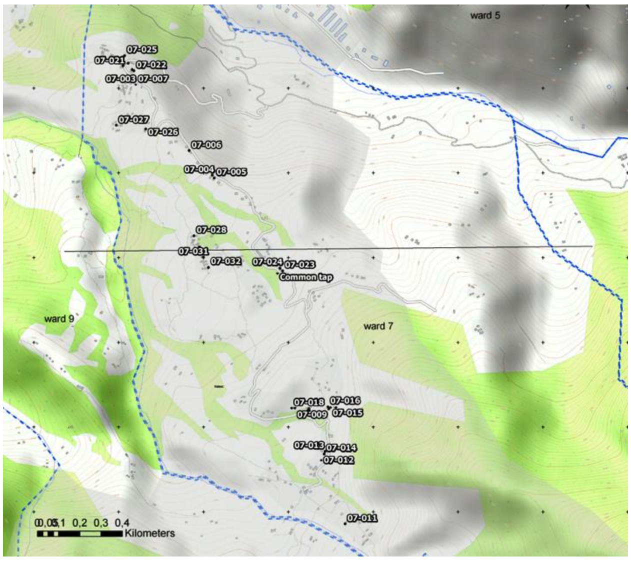
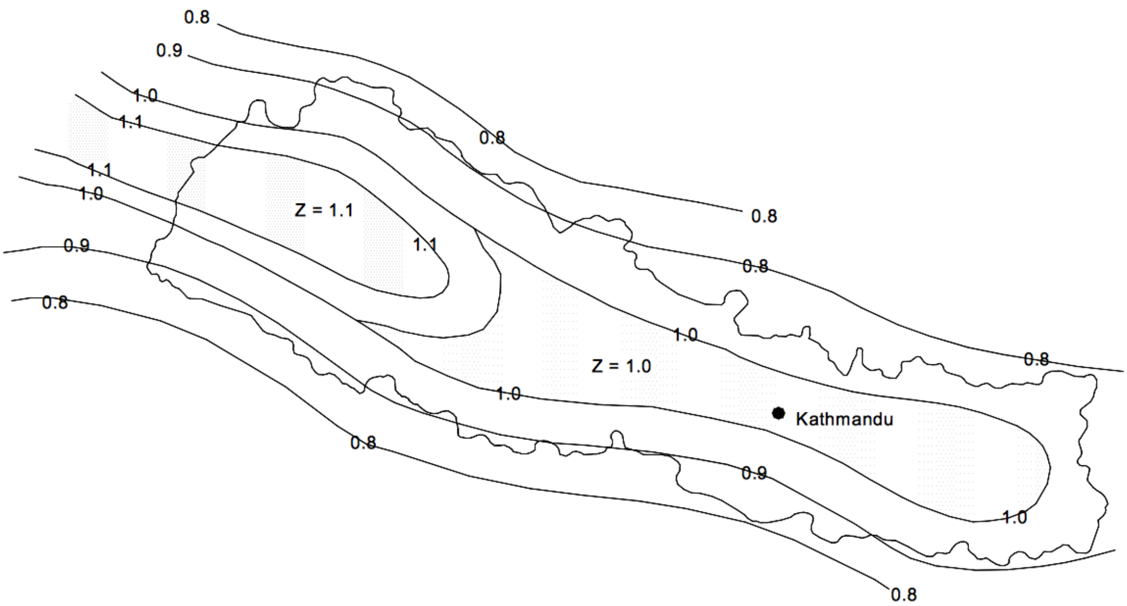


Figure 73. Map of beneficiary houses of AWASUKA in Suping, by Marc Crespo

The ward of Suping is a rural area with houses spread along cornfields and forest areas. Consequently of this landscapes, the accessibility to emplacements is difficult, especially of heavy materials. The best solution to face this problem is to move Bhimphedi's workshop on a new one up in the ward.

Also, as it has been commented below, Nepal is an area in hazard of earthquakes. Because of it, the government of Nepal drew a seismic zoning map for the entire country where different risky area were defined, according to their more probable magnitude of damage:



Zone	Zone Coefficient	Risk
A	Z ≥ 1.0	Widespread Collapse and Heavy Damage
B	0.8 ≥ Z > 1.0	Moderate Damage
C	Z < 0.8	Minor Damage

Figure 74. Seismic Zoning Map of Nepal and Zone specifications, by NBC

Concurring to this map, Bhimphedi (and Suping) is in the zone of risk A, the highest one, so the seismic safety elements have to be also the most resistant ones in the design of buildings.

- **Because of its construction technique**

According to budget, simplicity and how are the houses near the emplacements, the best solution corresponds to dhunga-mato construction style: foundations of cyclopic concrete[17] reinforced with Bamboo posts and walls made by stone and mud.

For this technique, have to be followed the methodology of work commented in previous sections, considering the anti-seismic elements.

10.2 NEPAL REGULATIONS

Nepal, as the rest of the countries, has a national building code that provides to its habitants a manual of standardized best solutions and recommendations for how to construct buildings in Nepal, considering different situations. It is called Nepal National Building Code (NBC), and it is redacted by the department of *Urban Development and Building Construction*, part from the ministry of *Physical Planning and Works*.

This code is divided into different specific guidelines. The one most suitable for this project is the called "*Guidelines for earthquake resistant building construction: Low strength masonry*", because, as its name indicates, treats anti-seismic houses constructed by low strength masonry (LSM), which includes mud and stone houses.

As foundation, the NBC proposes the use of strip footings, which helps the building to acquire the "box" behaviour chosen as anti-seismic system. Its dimensions will depend on the soil and the number of storey above:

[17] Concrete made by large stone, mud a little proportion of cement

SOIL CLASSIFICATION	DESCRIPTION OF SOIL TYPE	REMARKS
Hard	– Rocks in different state of weathering – Boulder bed and gravels – Sandy gravels – Dense or loose, coarse to medium, sand offering high resistance to penetration by tools – Stiff to medium clay which are readily indented by a thumb nail	
Medium	– Fine sand and silt (dry lumps easily pulverized by the finger) – Moist clay and sandy clay that can be that can be indented with thumb pressure	
Soft	– Fine sand loose and dry – Soft clay indented with moderate thumb pressure	
Weak	– Soft clay that can be penetrated several centimetres with thumb – Wet clays	Buildings shall not be constructed in weak soil.

Note:

- *Soil type assumed to be same throughout the site.*
- *Foundations not required for hard rock bed.*
- *LSM building shall not be constructed in weak soil.*

Table 19. Soil classification and its description, by NBC

SOIL TYPE	Nº OF STOREY					
	One		Two		Two plus attic	
	Width	Depth	Width	Depth	Width	Depth
Hard	750	750	750	750	750	750
Medium	750	750	750	750	750	750
Soft	750	750	900	750	900	750

Table 20. Foundation dimensions depending on soil type, by NBC

Once had the dimensions of the foundation, its material and disposition should be as the following:

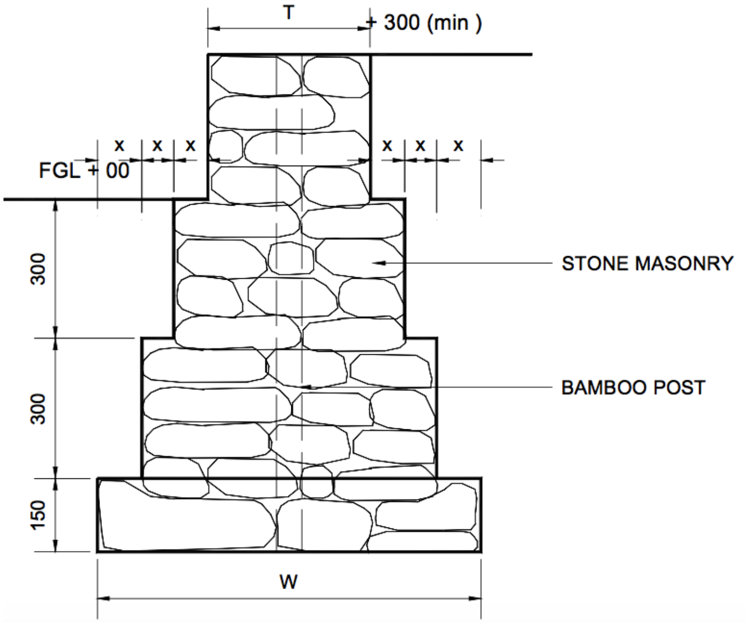


Figure 75. Stone and mud foundation: Specifications and graphical disposition, by NBC

- Masonry units shall be large flat-bedded stones
- Mortar joints shall not exceed 20 mm in any case.
- All the vertical joints shall be kept staggered in alternate layers.
- Mud packing in the core of foundation shall not be permitted.
- The gaps in the core shall be well-packed with the masonry units.

10.3 FOUNDATION DESIGN

A building process of design doesn't consist in just taking values from tables and from standardised codes or regulations. The results obtained must be interpreted and adapted to the reality of the project. In this case, making just use of the Nepal National Building Code could have been probably a mistake, because cases contemplated are general and not the optimal for each house.

Therefore, the design detailed below is considering a fixed value of width (the specified in NBC) and with it find the exact optimal depth of foundation (adaptable to different type of houses), capable to suffer its load without causing the soil's failure and considering the earthquake hazard of Nepal's area.

To obtain it, must be calculated the ultimate bearing capacity of the studied soil in seismic conditions.

10.3.1 NBC BASES

Concurring with the previous geotechnical study and according to the categorisation of the NBC, the soil where will lay the foundation is a soft to medium soil. Consequently, the dimensions for footing proportionated in the guideline, are the following:

SOIL TYPE	Nº OF STOREY					
	One		Two		Two plus attic	
	Width	Depth	Width	Depth	Width	Depth
Medium	750	750	750	750	750	750
Soft	750	750	900	750	900	750

Table 21. Dimensions for foundations on soft to medium soils, by NBC

10.3.2. CALCULATION

Bearing capacity defines the load that a soil foundation can sustain at the state of incipient failure. In the static case, the bearing capacity Q_u is usually calculated by superposition of the contributions from surcharge loading q, soil cohesion c, and soil unit weight γ. For shallow strip foundations under vertical central loading, Terzaghi (1943) proposed to use the following expression:

$$Q_u = c \cdot Nc + \gamma \cdot D \cdot Nq + 0.5 \cdot \gamma \cdot B \cdot N\gamma$$

Where:

- Q_u = Ultimate bearing capacity
- C = Cohesion of soil
- γ = Unit weight of soil
- D = Depth of footing

- B = Width of footing
- Nc, Nq, Nγ = Terzaghi's bearing capacity factors[18] based on friction angle Φ.

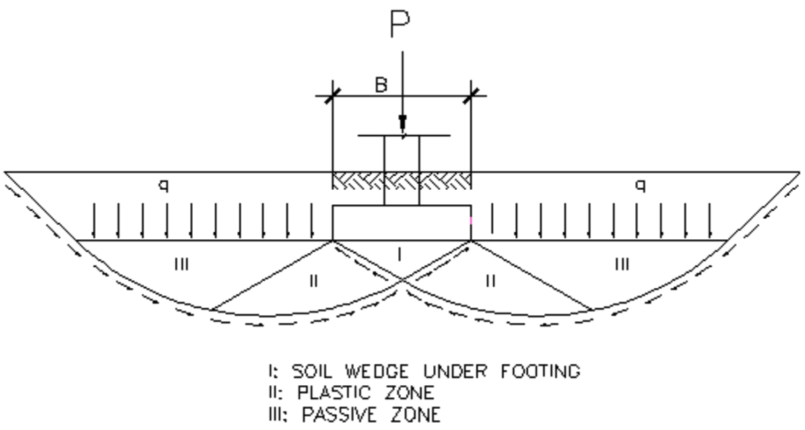


Figure 76. Theoretical static failure surface of Terzhahi

Thanks to the previous geotechnical study and the standardisation of bearing capacity factors, all data is available to calculate the ultimate bearing capacity at each depth of foundation.

C	25,5 kPa
γ	1700 kg/m³
B	0,75 m
Nc	17,5
Nq	5
Nγ	7,4

Table 22. Soil properties of Suping

Depth	Q_u	Q_u
[m]	*[kg/m²]*	*[kPa]*
0,75	13068,75	128,16
1	16213,75	159,00
1,15	18100,75	177,51
1,3	19987,75	196,01

[18] Tabulated non-unit factors designed by Terzaghi used to correct the bearing capacity from load, soil's cohesion and terrain at an specific angle of friction.

1,5	22503,75	220,69

Table 23. Static ultimate bearing capacity according to Terzaghi

But, as was initially mentioned, solutions of Table 13 just consider the static conditions of a soil. Many author have studied about the seism influence on soils as its bearing capacity, because is logically understandable that the resistance to being load of a soil decreases when an earthquake is happening, but the complex question is about how much is the difference.

To adapt the ancient equation of Terzaghi to seismic conditions is as simple as to be multiplied by a coefficient. This coefficient must be related with the acceleration of the possible earthquake, more specifically, it depends on the horizontal component of this acceleration (vertical component can be assumed as null)

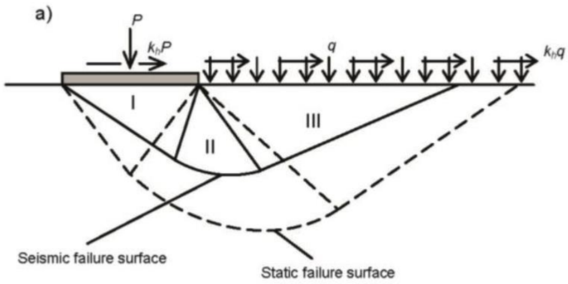


Figure 77. General model for analysis and static and seismic failure surfaces, by Budhu & Al-Karni

$$Q_u = c \cdot N_{c,E} + \gamma \cdot D \cdot N_{q,E} + 0.5 \cdot \gamma \cdot B \cdot N_{\gamma,E}$$

Where $N_{c,E}$, $N_{q,E}$ and $N_{y,E}$ are seismic bearing capacity factors

$$N_{x,E} = N_x \cdot K_h$$

$$K_h = \frac{a_h}{gravity}$$

To consider a specific seism acceleration, for this design is going to be considered a seism as the one of 25th of April in Gorkha, Nepal. Taking the values from the national department of earthquakes of Nepal, the horizontal seism coefficient for this earthquake ware the following:

- Average horizontal acceleration during Gorkha's earthquake -> 200 cm/s2

$$K_h = \frac{200\,\frac{cm}{s^2}}{981\,\frac{cm}{s^2}} = 0{,}204$$

- Peak horizontal acceleration[19] during Gorkha's earthquake -> 250 cm/s2

$$K_h = \frac{250\,\frac{cm}{s^2}}{981\,\frac{cm}{s^2}} = 0{,}255$$

Several different authors studied the consequences of this coefficient into bearing capacity factors, so in ins in study have been taken different values found in the ages to take an approximated better solution of average.

K_h= 0,25	*Sarma & Iossifelis (1990)*	*Richards et al. (1993)*	*Budhu & Al-Karni (1993)*	*Soubra (1999)*	*Choudhury & Subba Rao (2005)*	AVERAGE
$N_{c,E}$	0,605	0,44	0,35	0,6	0,295	0,458
$N_{q,E}$	0,5	0,475	0,395	0,495	0,3	0,433
$N_{y,E}$	0,29	0,265	0,265	0,26	0,175	0,251

Table 24. Seismic Terzaghi factors considering a coefficient of Kh = 0,25

K_h= 0,2	*Sarma & Iossifelis (1990)*	*Richards et al. (1993)*	*Budhu & Al-Karni (1993)*	*Soubra (1999)*	*Choudhury & Subba Rao (2005)*	AVERAGE
$N_{c,E}$	0,67	0,52	0,42	0,67	0,37	0,53
$N_{q,E}$	0,58	0,55	0,49	0,58	0,41	0,522
$N_{y,E}$	0,37	0,35	0,29	0,35	0,23	0,318

Table 25. Seismic Terzaghi factors considering a coefficient of Kh = 0,25

	Static conditions		*During earthquake of 25th April of 2015*			
Depth	**Q_u**	**Q_u**	**$Q_{u,E}$**	**$Q_{u,E}$**	**$Q_{u,E,Peak}$**	**$Q_{u,E,Peak}$**
[m]	*[kg/m²]*	*[kPa]*	*[kg/m²]*	*[kPa]*	*[kg/m²]*	*[kPa]*
0,75	13068,75	128,16	6175,21	60,56	5089,80	51,26
1	16213,75	159,00	7816,90	76,66	6451,59	63,60
1,15	18100,75	177,51	8801,91	86,32	7268,66	71,00

[19] The peak acceleration corresponds to the maximum acceleration

1,3	19987,75	196,01	9786,93	95,98	8085,73	78,41
1,5	22503,75	220,69	11100,28	108,86	9175,16	88,27

Where: $Q_{u,\,E}$ = Ultimate bearing capacity during Gorkha's Earthquake
$Q_{u,\,E,\,Peak}$ = Ultimate bearing capacity Gorkha's Earthquake at its peak amplitude of horizontal acceleration

Table 26. Ultimate Bearing Capacities adapted to static and seismic conditions

As it is seen, the solution is open to as much bearing capacity as it is possible to suffer. This is because Suping houses are not exactly defined yet, but with this chart available, once the structure of a new house is defined, with the calculation of vertical stress at foundation level it is possible to decide the safest and accurate foundation.

In the table, there is considered two different seismic accelerations. Depending in the magnitude of the earthquake that though to resist, can be chosen the average acceleration of a severe earthquake as the one that hitted Nepal in 2015 or, if the houses are thought as long-term with possibility to resist bigger earthquakes or at its peak moment, it is possible to take the peak acceleration of Kh=2,5.

An example of methodology with the chart: if the vertical stress at level foundation is 35 kPa and the safety factor considered is 2 (so 70 kPa as bearing capacity), at static conditions, with 0,75m of depth's foundation the soil would had been able to resist without problems. But, considering seismic loads such as the average of Gorkha's earthquake, the minimum depth needed would be 1 m, and if considering the peak acceleration, 1,15m depth.

11. COOPERATION STAY

This practical part of the project has been principally in the emplacement of the program: in Bhimphedi (and Suping), Nepal. My stay has been for 33 days in Nepal and 25 days completely dedicated to the emplacement area (from 6th August until 30th August), co-working with the other AWASUKA volunteers and with Balmandir[20] volunteers.

[20] Local children's Home with the support of Amics del Nepal

My tasks during the stay have been diverse. The main task was to finish the geotechnical study about Suping soil and go personally to the emplacement area to recognise the terrain, but other tasks were assigned to me during this cooperation stay:

- *Support to architects*

The role of architects in the program is not only design the building from Barcelona, but going to Nepal as volunteers for 4 months and execute the project as head leaders. For that reason, once arrived there, one of my task was supporting them in their as supervisor of the construction of the prototypes, mostly with the dhunga-mato one.

Figure 78. Dhunga-mato prototype

- *Tester of material's quality*

Different materials are used for each prototype. At the moment of the trip, architects were finishing just dhunga-mato prototype, and changing some details of concrete block prototype also; but the following Suping dhunga-mato houses are planned to be started just after monsoon season. Consequently, I took the responsibility of doing the appropriate quality tests for the mud used for these new houses.

Resources for doing this kind of test are limited, so the tests I did for assure the mud was correct were more rudimental as workers do in Spain.

1. Direct manipulation: Adding a quantity of water (approximately 20-30%), manipulate with bare hands the soil. In this case the soil was very sticky and fine. It demonstrates being impermeable.

Figure 79. Hands during the testing

2. Jar test: In an empty bottle of plastic, add a considerable soil sample (1/3 of the bottle) and water until at least 3/4 of the bottle. Once mixed intensely, leave the sample 24-48h to sediment. With this test is possible to see the different soil type fractions, but in this case were all fines.

Figure 80. Bottle tested after 48h

3. Ball fall: Adding a quantity of water (approximately 10-20%), do a perfect sphere of soil of 4 cm of diameter. Once ready, it is thrown to space from a height of 1.5 m, and depending is final state, expresses its content. This time, as the sample is practically unaltered and with 4,5 cm of modified diameter, expresses that the soil has a high content of agglutinative clay, and low content of sand.

Figure 81. Original sphere and final state (left to right)

4. <u>Cigar test:</u> Adding a quantity of water (approximately 15-25%) prepare threads of 3 cm as diameter. Once done, they must be softly pushed into space over a non-porous surface. Depending on at which distance the “cigar” is broken transversally to the movement (because its own weight), determinates the cohesion of soil and its proportion of clay.

Figure 82. Proceed of cigar test to one thread

In this test, as the breaks were between 5 to 15 cm, the soil was resulted to be good enough in proportions of sand and clay.

5. <u>Biscuit test:</u> Adding a quantity of water (approximately 15-25%) put a soil sample into a round mould of 5 cm of diameter and 1 cm high (a homemade bamboo ring, in this case). Once left it drying as much time as they needed, approximately 1 week at sunshine, observing the “biscuit” and its shrinkage, it can be assured that the content of clay is good, because there are no perceptible cracks on samples.

Figure 83. Proceed of cigar test to one thread

After these 5 tests, the soil prepared for mud in Suping was considered as a one of good quality.

- *Research of cultural information*

Another task done there was to do research of different aspects of Nepali culture. This includes information about its culture and religions, about their actual architecture and about their traditional architecture, etc. The main purpose for this task was to produce a complete study about Nepali construction (this one is being read) and, thanks to this "in-person" research, many of the photographies that appears in this dissertation have been taken by myself.

All the information obtained is going to be voluntarily yield to Base-A for itself profit on its cooperation programs.

- *Logistics' support*

Afterwards the technical tasks assigned to all volunteers team, there is a lot of logistics work behind of it to solve the daily problems of organisation and planning. Because of it, during the days staying in Bhimphedi, I helped the team with its organisation and planning for the week. One of the most complicated and common tasks was to go shopping materials to the biggest town in the area: Hetauda. It is recommendable to always go two volunteers with the aid of a Nepali-Engilsh translator, so usually the persons in charge to go there were and architect and I, with the aid of Niranjan Pudassaine as translator, the coordinator of AWASUKA workers.

11.1 CONTINUITY OF THE PROJECT

AWASUKA program was initially planned to finish by the end of 2017, but the reality is that it has got delay on its plans. Right know, is probably just in the middle of the program; there are planned numerous interventions of "retrofitting" operations (adapt actual houses to earthquake resistance) and a long list of beneficiaries waiting for their houses to be built.

Regarding to foundations project, its continuity is just to adapt the given solution to the different houses that want to be constructed in Suping. In case of changing of ward and, probably, the soil type, it would be necessary to repeat the geotechnical study and adapt Terzaghi's equation to the new properties.

And finally, referring to my volunteering work in AWASUKA, now I will be 4 more months of support to the program from here, Barcelona, mostly for bureaucratic and logistics tasks and, if it is need, for another design or technical project.

CONCLUSIONS

This thesis has been constantly in a situation of duality. There have been differenced two “project types” since the beginning, with two areas of study each one, and concluding with two countries connected: Nepal and Spain.

Firstly, it has been done a theoretical research about Nepal’s reality and all needed to know about solving seismic hazards in buildings; and, once familiarised with the topic, it has been possible to design an anti-seismic foundation system according to a geotechnical study done of the soil of the emplacement. This whole project was my academic objective for this dissertation, and has been reached successfully in the time and order expected. Thanks to it, I’ve acquired knowledge about a new culture and its architecture, learnt several concepts about earthquakes and anti-seismic buildings (an area of engineering almost not treated in Spain), put in practise my geotechnical knowledge doing tests by my own for the first time, and done my first design’s calculation of a real constructive project.

About all this area, I conclude that, even Nepal is a developing country really far from being considered as developed, they already have knowledge and intention to learn about anti-seismic architecture for their houses. Most of current new constructions have anti-seismic elements on them, probably because of its detailed National Building Code, but also for their own understanding and logic after the devastation of 2015. Right now, their main problem in construction is to realise about finding the best solution for every situation, because it is often taken same measures for realities very different and, because of that, at the end sometimes they have taken a completely wrong proceed.

One example of it was doing a geotechnical simple study for these new houses. They don’t even consider the option of doing this tests for a simple house, but after seeing that European volunteering believed in his “preparations” before building, they got interest on it. If had to do another project, no doubt it would be to adapt all laboratory tests or in situ tests with instruments such difficult to obtain there, into practical and easy tests with whose have a basic knowledge about the soil properties.

Referring to the motivation for this thesis, my personal objective of working on a real project for people in need of technical knowledge, I conclude that it has been a recommendable experience of personal enrichment, academically and humanly. Nepal has an enormous potential of natural resources and human resources, but its constant exhibition to natural disasters and its current delay on development supposes a big difficulty to improve its developing situation. Because of it, it is a good synergy that students or workers from developing countries travel to Nepal to help the country, but, in my opinion, it always has to be in a cooperation intention and not volunteering, in order to not destabilise the sustainability of the country or causing dependency.

Finally, even the satisfactory results, it is needed to mention that there have been several problems and difficulties during the execution of this thesis. Examples of them could be the impossibility of calculating the natural moisture of the soil, because of the constant rains during monsoon season; the unviability on doing the initial objective of designing a system for treatment of residual water, because this dissertation would have pretended to take a range too wide for a single project; and, also, the lack of seismic tests for soil, caused by the difficulty of obtaining the necessary material.

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FIGURE SUMMARY

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