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Improved seismic-resistant design of adobe houses in vulnerable areas in Peru

- Raising seismic awareness in an Andean community

Elin Mattsson

IMPROVED SEISMIC-RESISTANT DESIGN OF ADOBE HOUSES IN VULNERABLE AREAS IN PERU

Raising seismic awareness in an Andean community

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Abstract

Improved seismic-resistant design of adobe houses in vulnerable areas in Peru

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During the last decades, many seismic reinforcement techniques of adobe houses have been developed. None of the techniques has however reached out to the people in need, mainly due to high costs. To prevent unacceptable seismic risks in rural areas, it is necessary to develop technology transfers along with training and educational programs.

PUCP (The Pontifical Catholic University of Peru) has started a training project on earthquake resistant adobe constructions, addressed to inhabitants in an Andean community. Their attention is set at this time, to the district of Pullo, which is located in a highly seismic area. 80 % if the population is living in adobe houses and more than 50 % of them are living in poverty. PUCP is leading an extensive project, which objectives are to work with people in order to make them aware of the vulnerability of unreinforced adobe houses, and practically lean the technique of reinforcement with nylon ropes, called halyards.

On the 24th of August 2014 an earthquake measuring 6.9 on the Richter scale hit the district of Pullo. The situation in Pullo was evaluated to be heavily affected but concluded not to be urgent. Therefore a training project instead of reconstruction program was planned. The initiative aimed to raise seismic awareness among the people, and transfer knowledge on how to build seismic-resistant adobe homes.

The work included in this report is part of the long term project at PUCP. Firstly, the acquired knowledge on adobe construction's techniques, seismic effect on adobe houses built using different methods is included. A more detailed description of the new developed construction system is introduced, which was obtained by the experience gained by direct part-taking on the training project. The training and experimental stage of the project development included experimental testing on different constitutive parts of the constructive system, such as reinforcing rope-knots, manufacturing of adobe scaled building models, training of a portable shacking table, and socio-anthropologic experiments performed in situ. The use of modified tensile experiments, visual observation led to a recommendation of two knots, which proved to bring about the best structural performance in relation to seismic resistance. The manufacture of scale-building models in combination to the portable shaking table proved excellent results for direct comparison of structural behavior as well as in-situ educational purposes, instructing the people of Pullo about the new system. The latter added a direct and deep impact on the people, which results are to be shown in the future, by the follow-up of the project and the construction of new houses using the developed system.

Key words: Peru, earthquakes, adobe, reinforcement, training tools, rope-reinforcement, portable shaking table.

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This degree project has been conducted within a project at PUCP. Parts of this final report will serve as base for future publications on the topic.

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Elin Mattsson

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1 Introduction

1.1 What is it an adobe building?

Adobe is a natural building material consisting sand, clay, water and some organic material (for example straw). Building with adobe is a very old method comprising local material to make bricks on site. Moreover, the sun dried adobe mud blocks are low-cost, readily available and a simple self-construction material. Additionally, adobe has excellent acoustic but also thermal advantages that make them warm during summer and fresh and cool during winter. A major problem with adobe houses are their poor response to earthquake ground shaking.

The lack of resistance against seismic forces is caused by its massive structure (heavy weight, low straight and brittleness) that attract large inertia forces (Blondet, Villa Garcia, Brzev, & Rubiños, 2011). The weakness in the masonry and the brittle failures ensue without warning and the structure is unable to resist it (A.Bolt, 1988) (Blondet M. , 2007). Vertical cracking, separation of walls at the corners, diagonal cracking in the walls, and out-of-plane wall collapse are typical earthquake damage patterns. Complete building collapse are often caused by lack of adequate wall-to-roof connections which lead to separations of the building elements (Blondet, Villa Garcia, Brzev, & Rubiños, 2011).

Earthquake damages on adobe houses doesn’t only lead to tragic deaths and injuries, but also it has an economic impact. In some countries, like Argentina and Chile, adobe constructions are banned because of its poor seismic performance (Blondet, Villa Garcia, Brzev, & Rubiños, 2011) (Blondet & Rubiños, 2010). An adobe house prone to earthquake forces is shown in Figure 1.1. Earthquakes occurring in developing countries shows reiterative times that people living in adobe houses are put at a great risk. This underscores the urgency to find simple, easy available and economic solutions to reinforce the adobe buildings (Blondet, Torrealva, Vargas, & Tarque, 2006).

Figure 1.1: Adobe house destroyed by earthquake in Pisco 2007 (Photo: M Blondet)

1.2 World distribution of adobe buildings

Use of adobe mud has been known for more than 9000 years (Houben & Guillard, 1994). Today it is one of the world's most widely used building material and common in many of the world´s most hazard-prone regions where dwellers cannot afford to purchase industrialized construction materials. Rural areas in Latin America, Africa, the Indian subcontinent, and some parts of Asia, the Middle East and Southern Europe distribute adobe buildings, in which half of the world´s population live or work (Houben & Guillard, 1994). The map in Figure 1.2 illustrates the wide spread of adobe. In many communities this type of constructions have a social stigma attached (Blondet, Villa Garcia, Brzev, & Rubiños, 2011).

Figure 1.2: World distribution of earth architecture
(Stroitelvsto, 2013)

1.3 Peru, a land of earthquakes aggravated by social difficulties

Per (Figure 1.3) is almost three times as big as Sweden, with a population of 30.8 million of whom 8 million live in Lima, the capital city (Utrikespolitiska institutet, 2014). Geographically Peru possesses three different climate zones; the coastal deserts the Andean mountains and the Amazon jungle.

Figure 1.3: Map of Peru (Utrikespolitiska institutet, 2014)

Kids start school at an age of six. Formally, eleven years of school is an obligation. 95 % of the population attends the first six years, but only four out of five continue to high school. The drop outs mainly occur in the country side where the kids are needed in work. Around a fourth of the people finishing high school continue to study at a university. The reading and writing skills are improving but still there are big differences between the city and countryside and between men and women (Utrikespolitiska institutet, 2014).

According to the Foreign Policy Institute of Sweden (2014) (Utrikespolitiska institutet) the most common work in Peru is within the service sector, second biggest employer are the mining industry. Over 50 % of the urban working population is counted to be within the informal economy. Included in this is also the agriculture for self-catering, which is the most common occupation in the countryside. The Foreign Policy Institute (2014) also points out the social inequalities and big difference in income that exists in Peru. In 2013 every third person was living in poverty. Over 6 % were living in extreme poverty. More than 20 % of children under five years and 10 % of the total population suffer from malnutrition.

Peru has a rich blend of cultures, but is dominated by the Spanish and Native American influences. The people in the highlands have strong Native

American traditions, but European elements are labeled in clothes, music and even traditions. However, there is a big gap between the cultures. Many small villages are organized almost like in the Inka times with common ground and collectively work. Figure 1.4 shows a typical dressed Peruvian girl from the Andean highlands. In these villages the natives live a life far from the western world's society (Utrikespolitiska institutet, 2014).

Peru has long struggled with social gaps and racism. Even though gaps between different ethnic groups nowadays are more floating, it is still problematic. There are traditional elite of Spanish descent, but the upper class also include other white people and a mixture of Spanish and Indians called the mestizos. The Asian people are thought to be middle class and the black minority is at bottom of the social scale. Furthermore, Peru sees many flaws within the welfare, especially in the countryside as the health centers and availability of doctors is concentrated in the big cities. Another contribution to this is that more than 20 % of all households lack pure water supply. The most common diseases are infections in the respiratory, gastric diseases, malaria and tuberculosis (Utrikespolitiska institutet, 2014).

Figure 1.4: Traditional dressed Peruvian girl with the for the sierra typical alpaca animal. (Dann Clothing, 2014)

Besides social problems, Peru faces a lot of cruelty through seismic damages. These are caused by the geologic fault line named the Ring of Fire (Hudson, 1992). One main explanation of the majority of earthquakes is in terms of plate tectonics. The outermost parts of the earth (the lithosphere) consist of several large and fairly stable plates. The coast of Peru spans along one of these plates, called the Nazca plate (A.Bolt, 1988). The position of the Nazca plate is shown in Figure 1.5.

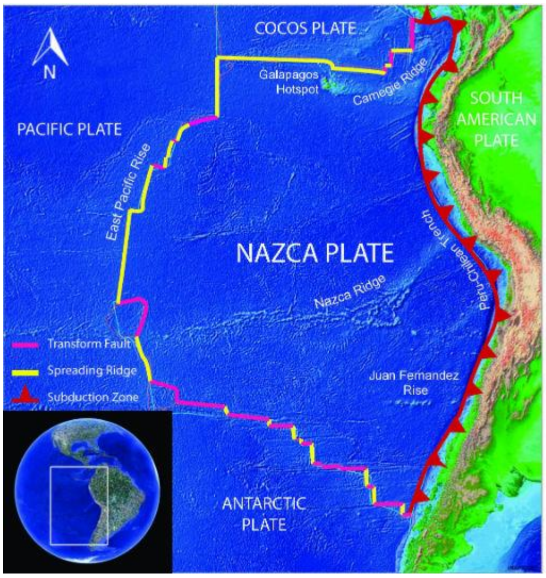


Figure 1.5: The Nazca Plate along the coastline of Peru (The watchers, 2011)

Figure 1.6: The Nazca plate's* movement beneath the *continent of South America Figure 1.6 demonstrated how the Nazca plate is forced beneath South America. The Andes, which abuts along the Pacific plate boundary, are created by these movements and poses a threat of earthquake hazards (Hudson, 1992).

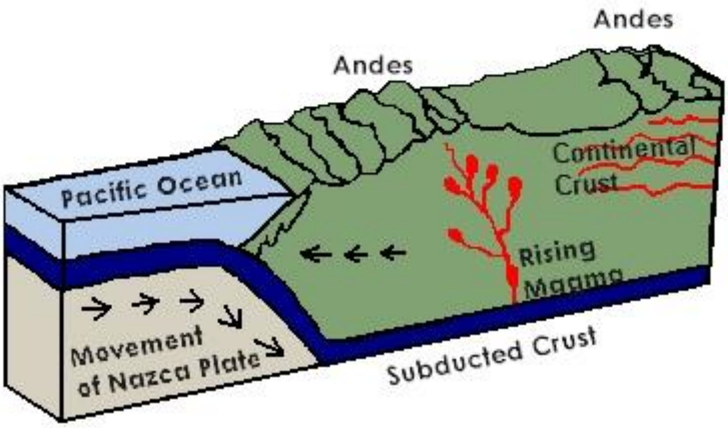


Figure 1.6: The Nazca plate's movement beneath the continent of South America (Shleyf, 2012)

The earthquake danger is not the same everywhere. Consequently, Peru has been divided in three regions by seismic risk; the desert with a high risk, the highland with medium risk and the rainforest with a low risk (Figure 1.7) (Blondet, Tarque , & Velasquez, 2006).

Figure 1.7: Seismic map of Peru (Class Adventure Travel, 2015)

Since 1568 there have been over 70 significant earthquakes in Peru (Hudson, 1992). In 2007 the latest chapter in Peru's long history of earthquake destruction began. An earthquake measuring 8 on the Richter scale, and with more than 500 aftershocks hit the coast, and leveled Pisco, a city of 80000 inhabitants as well as the smaller towns of Chincha and El Carmen (Insight guides, 2006). About 600 people were killed but more than 300000 were affected. The earthquake destroyed more than 75000 dwellings which equaled about 80 percent of all adobe buildings in the area (Blondet M. , 2007). Figure 1.8 points out the extents of the damages in Pisco.

Figure 1.8: The damages of adobe house in the Pisco earthquake of 2007 (Clark, 2013).

Earthquakes occurring in developing countries repeatedly put millions of people living in adobe houses at great risks. The future will likely see more disasters as people will rebuild and continue living in the vulnerable areas (Brumbaugh, 2010). A large amount of deaths caused by earthquakes in Peru can be blamed on collapsed or damaged adobe houses (Blondet, Villa Garcia, Brzev, & Rubiños, 2011). Comprehensive earthquake damage statistics from around the world demonstrate the urgency to find simple, easy available and economic solutions to improve the performance of adobe buildings (Blondet, Torrealva, Vargas, & Tarque, 2006).

1.4 Seismic deficiencies of adobe house structures

In Peru adobe construction is the only viable alternative for many families (Blondet M. , 2007). Therefore, at present, 35% of all houses (more than two million houses) are made of adobe or rammed earth in which almost 9 million people live (Serrano Lazo, 2014). Traditional adobe houses in the Peruvian coast line and highlands have followed practice for over 200 years (Loaiza, Blondet, & Ottazzi, 2014). These adobe houses, built with no technical assistance, have long suffered significant damages during earthquake ground shaking.

Seismic deficiencies are caused by poor mechanic characteristics, such as heavy weight, low strength and brittleness (Blondet, Villa Garcia, Brzev, & Rubiños, 2011). The massive walls attract inertia forces. The weakness of the masonry makes it impossible for the walls to resist forces, leading to sudden brittle failures (Blondet M. , 2007). Vertical cracking and separations of walls at corners, diagonal cracking in the walls, and out-of-plane wall collapse are an enumeration of typical crack patterns. Figure 1.9*Figure 1.9:* Seismic deficiencies on adobe buildings

(Blondet, Villa Garcia, Brzev, & Rubiños, 2011) is summing up the common seismic deficiencies on adobe house structures.

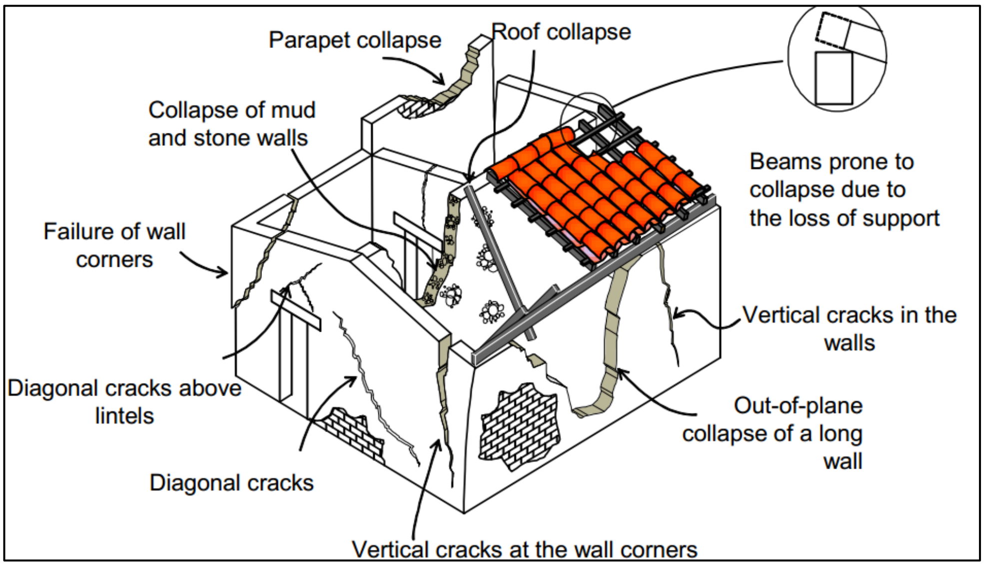


Figure 1.9: Seismic deficiencies on adobe buildings
(Blondet, Villa Garcia, Brzev, & Rubiños, 2011)

In calculations, earthquakes are treated as horizontal forces (comparable to wind forces) (King, 1996). Bolt (1988) points out that this can be misleading, as earthquake shaking and damages are caused by three different types of elastic waves. Furthermore, earthquake forces are unpredictable as they reverse, repeat and can come from any direction. The dynamic properties of earthquakes can generate tremendous forces on structures, shown in Figure 1.10 (King, 1996).

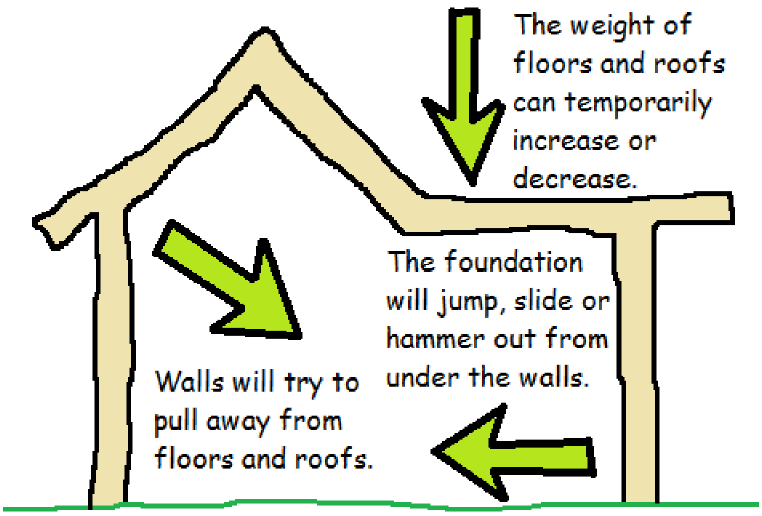


Figure 1.10: Damages caused by seismic forces (King, 1996)

As an earthquake occurs, structures are hit by in-plane and out-of-plane forces. The wall geometry and stiffness of roof and floor that carry loads into the wall are critical factors for the amount of in-plane forces. There are different reasons for the appearance of cracks. If a shear force hits the building, different openings tend to move further apart which creates a line of tension. When the force subside, a diagonal crack is likely to appear in opposite direction. In line with that walls try to change shape all openings will be put under tension, try to open and create more cracks. In this situation the walls have lost the capacity to resist tension and shear forces. Figure 1.11illustrates the cracks that can appear due to in-plane forces. Additional loads on the structure will cause complete failure or collapse. According to this, the size and location of the openings are crucial to the stability of the structure (King, 1996). Quin (2014) states that an adequate building should have windows and doors centered in the walls to create symmetry.

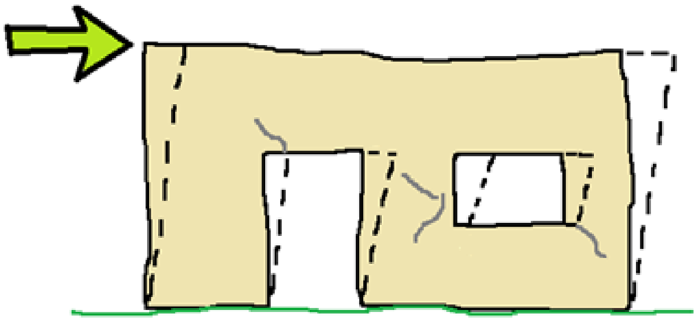


Figure 1.11: Cracks appearing due to in-plane forces
(King, 1996)

Out-of-plane forces tend to push the face of the wall inward or outward, see Figure 1.12***:*** Wall behavior due to out-of-plane forces (King, 1996). Crucial is the securing attachments, between wall and floor and roof, as they affects how the wall will bend. Furthermore, the floor and roof must be strong enough to transmit reactions that appear. Therefor connection plates, bolts and straps must be carefully designed for a wall with support at top. A freestanding wall depends on the earth pressure and width of the footing (King, 1996).

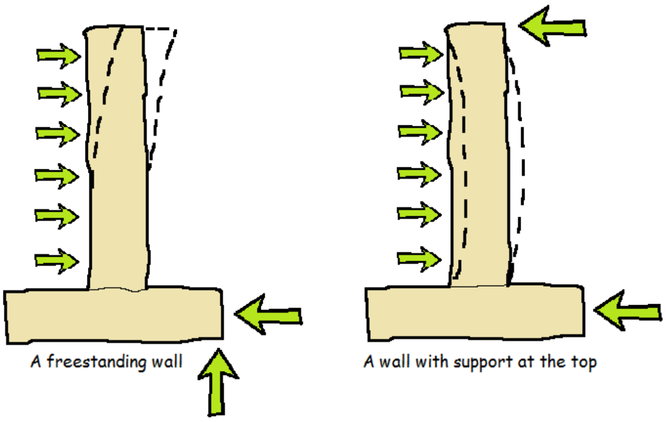


Figure 1.12: Wall behavior due to out-of-plane forces
(King, 1996)

1.5 Improved earthquake performance

According to the economic situation in Peru, many dwellers have no possibility to technical assistance neither in construction nor design. Because of informal building many houses sees structural deficiencies, are built on poor grounds and are seismically vulnerable (Blondet, Tarque , & Velasquez, 2006). Seismic risks can be measured in terms of hazards and vulnerability. Hazards include problem created by seismic features in terms of earthquake magnitude, typography and soil properties (Tarque, 2015). Safe places to build houses are far away from natural hazards with flat land, and on strong soil or rock (Blondet, Tarque , & Velasquez, 2006).

Vulnerability, on the other hand, is issues related to the buildings. Evaluation of the vulnerability has to determine if the houses are well constructed, have adequate wall density (enough of walls in different directions), and the quality or condition of the present building (Tarque, 2015). Blondet et al. (2011) summarize main recommendations for improved seismic performance as following:

- Structures should be tied together
- Light, well connected roofs
- Good quality construction
- Flat, firm and dry site
- Buttresses and pilasters
- Regular and symmetrical structure
- Horizontal and vertical reinforcement

To achieve an adequate construction quality, the soil properties are of great importance. Adobe consists of sand, clay, water, and an organic material that binds the bricks together. Clay is the most important component as it provides dry strength. Simple field tests (dry strength tests, roll test, etc.) can be performed to control the selection of adequate soil. Marcial Blondet et al. (2011) give a summary of the most relevant tests and recommendations.

The planning of the building should be regular and symmetric, simulating the principle of the compact box-type layout Figure 1.13. Walls should be built on a foundation made of concrete. Joints between the adobe bricks and overlapping courses should be uniformed and completely filled with mortar. A layer of mud plaster (a mix of mud and straw) should be added to give protection and durability to walls (Blondet, Villa Garcia, Brzev, & Rubiños, 2011).

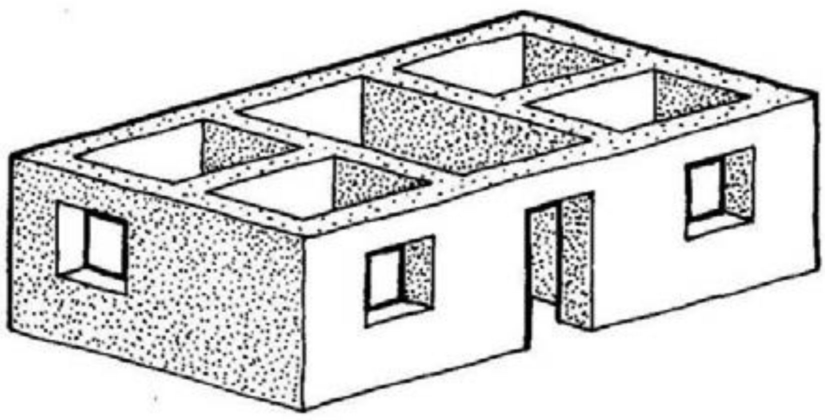


Figure 1.13: Compact box-type layout (Blondet, Villa Garcia, Brzev, & Rubiños, 2011)

According to Blondet et al (2011), buttresses and pilaster are at significant importance to ensure adequate seismic safety. Contributions of the building elements include an overall stabilization, increased strength and prevention of inward or outward wall collapses. Furthermore, Blondet et al. (2011) position the collar beams as one of the most essential assessments to prevent earthquake damages. The beam ties the walls together which prevent separations under seismic forces. To achieve wanted features, the collar beam need to act like a belt, be strong, continuous and secretly tied to the walls. Wood is a recommended material, but eucalyptus logs or bamboo are also sufficient. Finally, wall reinforcement should be applied to protect critical locations from collapse due to tensile stresses.

About 40 years ago PUCP started a research project to find reinforcement techniques to prevent collapse under severe earthquakes. The first tests were performed with a tilt-up table that simulated the inertial earthquake forces. Several reinforcement techniques were evaluated, but an introduction of whole bamboo canes in the interior of the walls were concluded most efficient. In 1984, the entrance of a unidirectional shaking table made it possible to perform full-scale tests subjected to constantly accelerating seismic motions. An internal cane together with a wooden ring beam (to avoid out-of-plane damages) were proved capable to resist a significant amount of dynamic shaking. Additionally, an importance founding at this stage was the essentiality of both horizontal and vertical reinforcements (Torrealva, Vargas Neumann, & Blondet, 2006).

Between the years of 1990-2000, PUCP focused on reducing the seismic vulnerability of existing buildings. The outcome of the period was a improved seismic behavior with welded steel mesh at both faces of the wall. In 2003, a polymer mesh was introduced. Severe shaking table tests concluded that the mesh confines the adobe walls from damages of earthquake forces (Figure 1.14). The latest chapter of research had its beginning in 2013, when Blondet et al. (2014) proved nylon ropes to be a successful reinforcement technique.

Figure 1.14: Adobe walls reinforced with polymer mesh (GEM Admin, 2013)

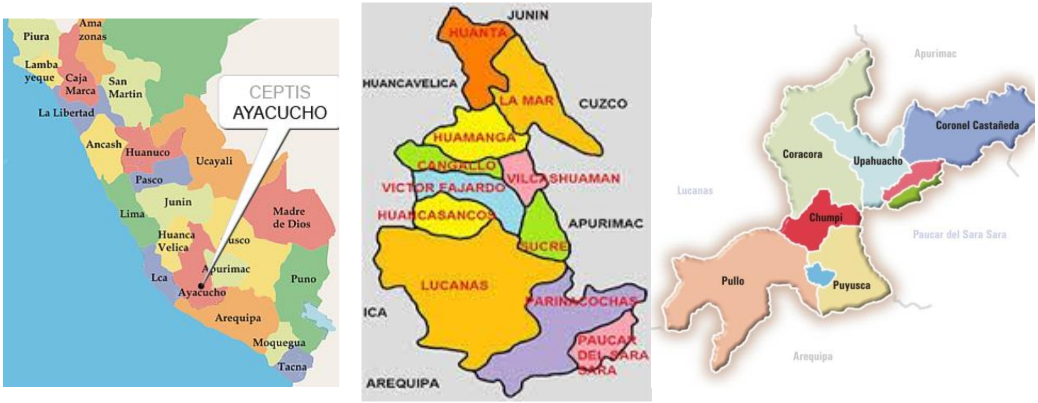
Considering the great amount of population inhabiting adobe houses in earthquake vulnerable areas, it is essential to reach out with the information on how to prevent future damage and house collapse. Until today, none of the successful techniques found has reached the targeted people. The difficulties of basic earthquake resistant building criteria don't lay in its construction but in creating awareness among the population. After an earthquake, reconstruction programs can be helpful, but in a long term point of view, the population need to get the ability to protect themselves from the danger, and be agents of their own lives.

1.5 PUCP's long term project of seismic reinforcement of adobe buildings

1.5.1 Seeking out for help

On the 24th of August 2014 an earthquake measuring 6.9 on the Richter scale hit two provinces, Lucanas and Parinacochas, in the state of Ayacucho. An evaluation made by Caritas Caravelí (an organization supporting missionary work for the Catholic Church and responsible for the parishes in the area) identified the district of Pullo as most affected of all communities. Figure 1.15a-c shows the geographic location of the areas. In a damage assessment of Pullo, the INDECI (2014) reported 105 people to be injured but an additional 100 to be indirect affected. Moreover, 26 homes became uninhabitable and further 29 damaged.

To prevent similar situations in the future, the Caritas Caravelí turned to PUCP (The Pontifical Catholic University of Peru) in order for help. Together with PUCP´s academic department of social responsibility (DARS) they decided upon a training program in developed building techniques and reparation of unreinforced adobe houses (Cribilleros, et al., 2014).



(a) (b) (c)

Figure 1.15: (a) Ayacucho (Ceptis, 2015), (b) Parinacochas (Prelatura de Caravelí , 2005), (c) Pullo (ePeruTours, 2015).

A study carried out by Cribilleros et al. (2014) shows that the situation of Pullo is very complex; not only the territorial but because of all social, economic and cultural realities that contrast each other. The earthquake had not generated an emergency situation from a technical aspect. The adobe houses were severly damaged, even if not critical. All homes are built with unreinforced adobe due to a lack of other resources and also poverty, they lack of basic criteria and many are old. Furthermore, the study concluded that the earthquake had a significant impact on the mental health.

Cribilleros et al. (2014) also found that the inhabitants are relatively seismically conscious. However they showed a passive attitude and lack of believe in that the government will solve their problems. On the other hand they do not consider the alternative of making proposal to solve their own problems. There is a general a good willingness of the community to work together with the university on training of seismically reinforcing of adobe houses. The people in this community are interested on improving their housing conditions.

1.5.2 A complex situation

Pullo has an area of 1572 square kilometer (National Statistic Institue of Peru, INEI, 2007). Reported by the National Statistics Institute of Peru (INEI (2013)) the population of Pullo reached an amount of 4848 inhabitants in 2013. INEI (2013) also reports Ayacucho to be one of the most undeveloped areas in Peru. 51,9 % of total population is poor and 16,1 % live in extreme poverty, which can be compared to the national average of 23 % poverty and 4,7 % extreme poverty.

The study carried out by Cribilleros et al. (2014) found that the district struggles with more difficulties than poverty. First, most of the population has no access to water, sewerage or public lightning. Furthermore, there are many social problems such as domestic and sexual violence, teen pregnancy and school dropouts. Additionally, Pullo has only six health centers supporting the entire area (1572 km^2). The health-care suffer because of poor infrastructure conditions, lack of basic services and availability of communication. The most common diseases are; pneumonia, bronchitis, stomach upsets, colic, dental infections and tooth decay. Pullo distribute 39 educational institutions. One of the greatest difficulties in the field of education is illiteracy; 13, 7 % of population but a higher percentage in the group of women (National Statistic Institue of Peru, INEI, 2007).

Cribilleros et al. (2014) also state that Pullo is a renowned livestock area. However, livestock farming is only a complementary activity to agriculture, which for a long time has been the main source of income. Recently, mining has begun to be a more important economic activity but has a strong presence (80 % of total production) of informal mining.

The capital of Pullo is the Town Center with a population of 400 inhabitants. Most of the population is concentrated in two of twelve suburbs due to mining activities. Furthermore, Pullo includes different altitudes, stretching from 500 meter up to 4000 meters above sea level (ASL). The capital is located at a level of 3030 meters ASL. The reality in Pullo is very complex due to its geography and socio-economic diversity. The capital as well as many suburbs at a high Andean level with few inhabitants engaged in agriculture in combination with intense processes of migration contrast with the situation in the suburbs at low altitude. In the lowland population is concentrated in certain areas, as well as they have intense mining operations (Cribilleros, et al., 2014).

1.5.3 A well-organized plan towards making a difference

To evaluate the possibilities to set up a cooperation program with the inhabitants in the community of Pullo, an interdisciplinary team made a first visit on November 2014. The objectives with the first field trip were to evaluate the aftermath of the earthquake, both on infrastructure and also on the mental health of the inhabitants (Cribilleros, et al., 2014).

The first visit Cribelleros et al. (2014) made to the site of Pullo, concluded that the situation of the site is not urgent. Therefore the idea of a training project instead of reconstruction program seemed more adequate. The psychologist on the team, Gabriela Gutiérrez (2014), suggested that the project group needs a second trip to make a proposal to the community and collect additional data: young peoples´ needs to design the youth center, information on how the population feels about adobe houses in a deeper way, authorities' interest on the project and others.

A long-term project, led by the DARS in association with Dr. Marcial Blondet at the Civil Engineering Division, involves working with people to make them aware of the vulnerability of unreinforced adobe houses. The final goal of the project is to educate people so that they can become agents of their own development. This will be done by transferring enough skills, so that the target people can build their own seismic-reinforced homes. Practical knowledge on reinforcing techniques using nylon strings will be passed on. In accordance with Blondet and Rubiños (2010) this is a starting point to tackle complex and multidimensional problem due to the social gap between academia and communities. To incite this, short-term plan includes building practice and with reinforcement by the dwellers on Pullo. It is expected that this project can be applied with equal effectiveness in other seismic areas where adobe buildings are dominant. The project will proceed in three phases.

Phase 1 will aim to create seismic conscience on earthen dwelling´s vulnerability and awake people´s interest on how to build safe adobe houses. It will present the materials and communication tools: a portable vibrating table to demonstrate the effectiveness of the reinforcing system, an adobe construction manual and a motivational video.

Phase 2 will focus on teaching community members how to build improved earthquake-resistant adobe houses by building a youth center with the participation of the population in the community. The training experience of the people will be investigated.

Phase 3 are a follow up phase of the community to see if the construction techniques taught and the reinforcement materials recommended are being used or not in new earth constructions. Conclusion on the effectiveness of the training process and replicability of the project in other seismic vulnerable communities will be investigated (Cribilleros, et al., 2014).

1.6 Step-by-step towards the long term goals- scope of this thesis

Scientist Paul Jr. Graham McHenry (1983) and Bruce King (1996) have long understood the importance of spreading good building criteria of adobe house structures. Brumbaugh (2010) explains earthquakes scientifically, but also highlights a social impact on people affected by seismic hazards. PUCP among other institutions, such as Bureau of Indian Standards (1993), have developed numerous of operational reinforcement methods and guidelines. Nevertheless, the population keep building with traditional un-reinforced techniques leading to tremendous situations both economically (house damage) and socially (mental impact). This underscores the importance of continues researching.

In 2013 Marcial Blondet et.al (2014) found that reinforcement with nylon ropes are very successful. As ropes are an available material and no mechanical assistance is necessary in the building process, the system was thought to be accessible for people in rural areas. Nevertheless, the method lacks economic efficiency due to the use of expensive turnbuckles. A long term project, developed by PUCP and Caritas Caravelí, seeks to implement the subjected reinforcement technique on the construction of adobe houses. As a starting point, the project is directing an Andean community, named Pullo. To get the purposed method affordable for the inhabitants, an efficient replacement of the turnbuckle needs to be found. It is thought that knots can be the answer, but their behavior has to be compared to those of the turnbuckle.

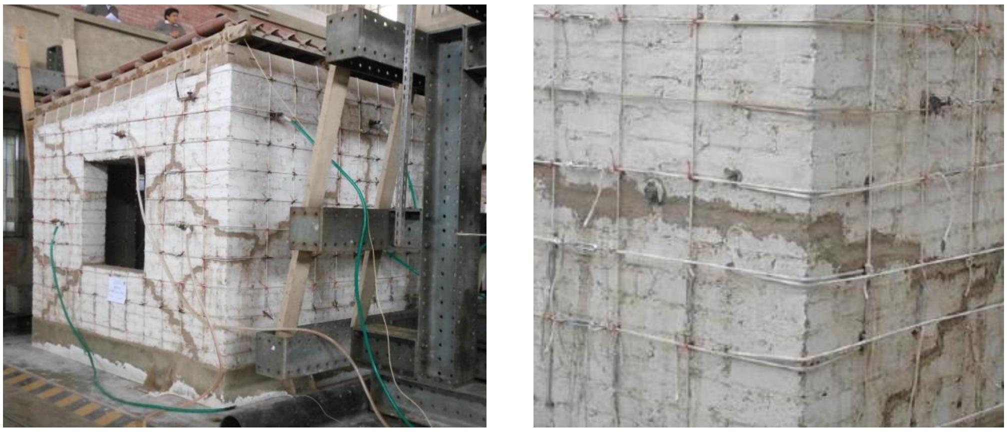
The visit to Pullo, carried out by Cribilleros et.al (2014), did not gather enough information on the existing building situation to set up a reconstruction program. Furthermore, to make the inhabitants join the training project, a seismic consciousness and willingness to cooperate need to be established. Therefore a second visit is planned. The visit seeks to begin the implementation of the rope-reinforcement by impressing upon people the consequences of living in seismically unsafe homes. A portable shaking table, developed by Marcial Blondet and Alvaro Rubiños (2010), is planned to be brought on the second trip in order to enhance understanding of the performance of simple structures under impact of earthquakes. However, to achieve desired results, the equipment requires improvement to meet the specific housing culture that presents Pullo.

This report seeks to evaluate the efficiency of replacing expensive tensile materials with simple knots. Furthermore, it will describe the development of the shaking table. In order to measure its impact, a demonstration with the device will be performed in Pullo. The demonstration also seeks to reach out to the people by involving them on an in-field workshop. Finally, the condition of existing buildings is to be investigated. The findings are documented in this thesis, and will serve as a base for continuous seismic risk evaluations of the area. To achieve the goals of this project, a combination of literature review, experimental testing, qualitative analysis and social techniques were applied.

To sum up; three subjects investigated in this report will as a unit try to contribute to a better environment for people in rural areas in Peru. The tensioning knots, portable shaking table and situational evaluation and raising of the seismic awareness will be introduced in following sections.

1.6.1 Reinforcement with nylon ropes and tensioning knots

In a full scale dynamic shaking test, Blondet et al. (2014) proved that nylon ropes, named halyards, are an effective way to seismically reinforce adobe houses (Figure 1.16a). The system consists of covering the walls with equally spaced, horizontal and vertical ropes, tensioned with turnbuckles (Figure 1**.**16b). It was shown that the reinforcement helped to maintain structural integrity and stability. Furthermore, it prevented partial collapse and separation of the walls during shaking (Blondet, Vargas, Sosa, & Soto, 2014). A disadvantage of the mentioned method was the cost of the metallic turnbuckles. To overcome this disadvantage, it was decided to replace the expensive tensioning material. This was thought to be done by including simple knots that could add and maintain the necessary tension on the ropes, providing stability to the adobe houses. It is expected that without this element the reinforcement's price could be reduced while preserving its safety and effectiveness (Blondet, Vargas, Sosa, & Soto, 2014).



(a) (b)

Figure 1.16: (a) Reinforced full scale model. (b) Detail of the reinforcement (Blondet, Vargas, Sosa, & Soto, 2014)

Sosa (2015), started to study different types of knots. He found three basic types and selected four combinations which behavior could be comparable to a turnbuckle.

This part of the report thesis includes the work done in order to study the four proposed combinations of knots, and compare their behavior to that of the turnbuckles. Attention was set to their workability, as well as the study of their effectiveness in maintaining tensile stress over time. Furthermore, this report seeks to recognize information which is important for the continuance of development and processing this reinforcement system. As outcome of this work, knots that could be used as replacement for the more expensive turnbuckles were designed. The information and resulting from this thesis will be implemented in the design of synthetic halyards as part of a reinforcement system.

1.6.2 Portable shaking table – testing of the samples

The idea of the portable shaking table (Figure 1.17), named "the bicycle", was born intending to raise seismic awareness. The device was to compare the construction systems currently used, with improvements that can be implemented among ordinary people. The concept of the bicycle dates from the year 2007, starting as a pilot project aiming to develop better tools for the education and training on safe and improved adobe houses. The intended target was communities located in seismic areas where building with adobe is traditional and building techniques are limited by their financial situation. Together with the bicycle an adobe tutorial, a motivational video, a technical video, and a portable shaking table were developed (Blondet & Rubiños, 2010).

The main purpose of the further development of the portable shaking-table is on-site demonstrations in order to persuade and convince inhabitants of seismically unsafe houses, of their own abilities to improve their houses, and demonstrate the methods in a practical and direct manner. The so called bicycle is a tool to pass on the understanding of how simple structures with or without reinforcement behave under seismic forces. This includes increasing awareness of the consequences of living in seismically unsafe houses. Main elements of the investigation are; self-help, cooperation and education.

Figure 1.17: The Portable Shaking Table (Blondet & Rubiños, 2013).

The shaking-table consists of a modified bicycle with a 60x60 cm platform where the sample is to be placed. The device is powered by one person by pedaling. Two different one-story high 1:10 scaled models will be tested simultaneously during a demonstration; one traditionally built without reinforcement (autochthonous adobe construction system) and one that is reinforced by a system developed at PUCP. The house model had to be easy to build, similar to existing houses. The difference between the traditional and the reinforced house had to be clear. The idea is that the unreinforced model will collapse in similar way as a real adobe house would during an earthquake, while the improved one will withstand the applied forces (Blondet & Rubiños, 2010).

In 2011- 2013 two scaled adobe houses were built and tested in the lab of PUCP. The models had 580 mm^2 base and 350 mm in height (Figure 1.18). The construction was made with traditional adobe. One of the models was reinforced with a plastic-wrapped mesh and covered with mud plaster. The models were first built on a wooden platform and then moved to the shaking table. The construction of the models took seven days. The unreinforced house showed failures similar to real adobe houses during earthquakes. The improved model had excellent seismic performance (Blondet & Rubiños, 2013).

Figure 1.18: To the left: Test of unreinforced model in 2011. To the right: Test of reinforced model in 2013 (Blondet & Rubiños, 2013).

This thesis includes the work done on creating, molding, assembling and testing scaled models of adobe houses using reinforcement simulating the tensioning ropes. The testing on the models includes a qualitative analysis of the outcome of the action of the applied vibrations. Furthermore, the research seeks to develop small scale adobe models, efficient for in-field demonstrations, but with the same outcome as previous tests (Blondet & Rubiños, 2013). Finally, experience of raising awareness is an important and concluding part of this study, as it reflects the reactions of the end-subjects of the whole project, which are the people.

The use of the shaking-table as part of raising awareness appears to be effective by observing the reactions of the people and the experiments performed as well. Although a follow-up in long periods of time is necessary to understand the extent of the impact of the demonstrations on the people’s perception.

1.6.3 Situational evaluation and raising the seismic awareness

As part of the work involved in the development of this thesis, a trip to Pullo was planned and executed. The field visit is included in latter was part of phase 1 of the long-term project. The main objectives with phase 1 are to create seismic conscience on earthen dwelling´s vulnerability and awaken people´s interest on how to build safe adobe houses. This was planned to do through a demonstration of the portable shaking-table to show the effect of the developed reinforced method on scaled models of adobe houses, and evaluate its impact on the people as a communication tool.

Moreover, a site evaluation sought to collect information on existing buildings´ characteristics so that a reinforcement program could be continuously improved. Furthermore, this thought to find those buildings that were put under high seismic risk, in terms of hazard and vulnerability. To meet priorities of both the research group and inhabitants, the key-buildings had to be carefully selected.

The visit to Pullo will serve the purpose to evaluate the situation, focusing on raising the seismic awareness among the people. The material collected will serve as a base for continuing working on the following phases of the long term project.

2 Material and methods

To achieve the goals of this project, a combination of literature review, experimental testing, qualitative analysis and social techniques were applied. A detailed explanation of the methodology used in order to complete each sub-section of this project is given below.

2.1 Tensioning knots

The tests of the knots were performed with double braided ropes, called halyard, acquired in a local Peruvian market (*Las Malvinas*). The ropes are common commercially on the Peruvian market. The dimensions of the ropes were chosen in case of availability. Three of the used ropes are depicted in Figure 2.1 In Peru, rope is sold in English units (1/2”, etc.). Henceforth the dimensions will be given in the metric system.

(a) Brand of a 3/16’’ (4,76 mm) rope

(b) Brand of a 5/32’’ (3,97 mm) rope

(c) Brand of a 1/8’’ (3,175 mm) rope

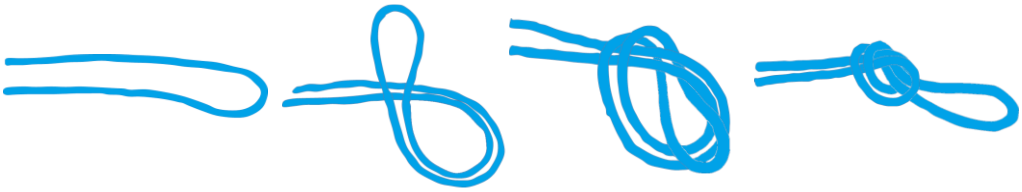
Figure 2.1: Different rope brands common commercially in Peru.

Following sections will first describe the implementation of the selected basic knots. Thereafter the combinations of these knots will be introduced along with the methodology of various tensile strength tests.

2.1.1 The Basic Knots

Three basic knots were found by Sosa (2015). All subjected configurations in following tests are combinations of these basic knots. The knots have different features, some serving tensioning, others the tying. In ability to replace the turnbuckle, both tensioning and tying are required. In order to improve a reinforcement of the adobe houses through tensioning ropes in a low-cost manner, four combinations of the basic knots were selected. In the instructions, the ropes/ends/ of ropes will be divided in actives a passives. The active rope/end is the one that will be put under motion, which means the actual tying. The other end or rope, which occupy a stationary position, will be called the passive end.

The first knot, called *The Overhand Loop* (Figure 2.2-2.3), is a simple knot which forms a fixed loop in a rope. The knot is likely to jam tight when the rope is being pulled. The intensions of The Overhand Loop is to create a loop in which another string can pass through. The knot is very strong and difficult to undo but still easy to implement. The tying starts by double the mainline to create a large loop, then folded over itself to make a second loop. The first loop will then be passed through the second loop and pulled tight.



Step 1: Double the mainline and create a large loop

Step 2: Fold the loop over so that a new loop is created.

Step 3: Pass the first loop in trough the second.

Step 4: Pull tight

Figure 2.2: Tying the Overhand Loop

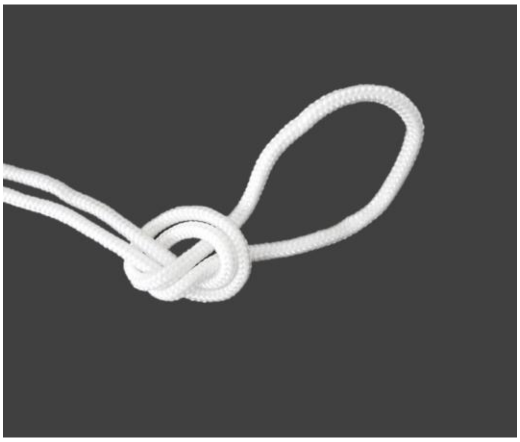
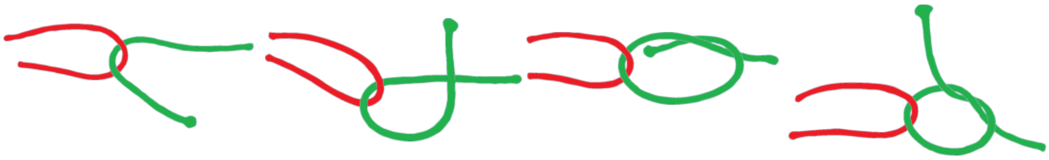


Figure 2.3: The Overhand Loop

Secondly, *the double Half Hitch* (Figure 2.4-2.5) which are used to binding as its name indicates. The number two states that the procedure must be repeated to secure the closure. The knot is easy and reliable. Furthermore, the knot is good for attaching the rope to another post and to maintain the tension of the rope. It is easy to deploy and difficult to untie. The knot also has advantageous properties as a stopper knot. To tie the Half Hitch you start by forming a loop around the post with the working end on top of the passive. Then the working end will be brought through the loop and pulled. Repeat this one more time and the double half hitch is completed. The rope is used to be tied around a post. In following instructions that post is another rope.

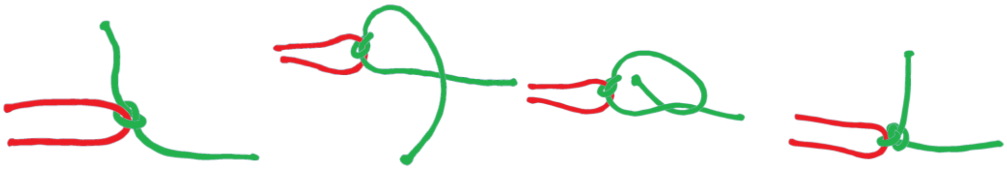


Step 1: Pull the active rope around a post.

Step 2: Put the active end over its passive end. A loop is created.

Step 3: Pull the active end through the created loop.

Step 4: Pull the active end. The first Half Hitch Knot is created.



Step 5: Tighten it even more by pulling.

Step 6: Put the active end over its passive one more time. Another new loop is created.

Step 7: Pull the active end through the created loop.

Step 8: Pull tight.

Figure 2.4: Tying the double Half Hitch

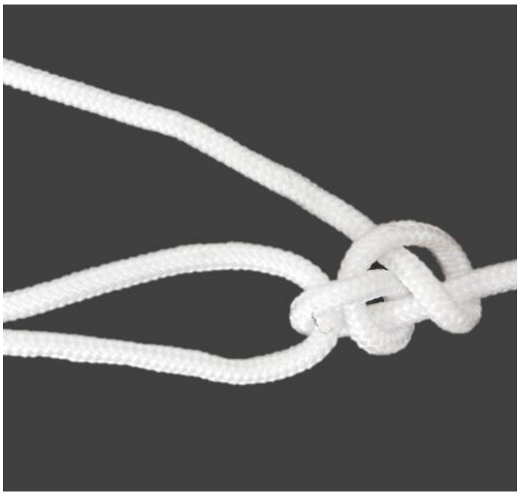


Figure 2.5: The double Half Hitch

Finally, *the Eight-Knot* (Figure *19*2.6-2.7) was selected. The name comes from its form. The general purpose is as a stopper knot which prevents the rope from running out of retraining devices. This type has the advantage that it can be untied even after the greatest strain. One drawback could be that without strain the knot might fall undone. Still having an easy implementation it could be found slightly more elaborate than previous knots. To tie the Eight-Knot, the working end is put over and then under the passive rope, creating two loops. The knot is completed by putting the working end through the first loop, from above, and then pulled to tension.

Step 1: Put the active end over its passive rope. One loop is created	**Step 2:** Put the active end under the passive rope so that a second loop is created.	**Step 3:** Put the active end through the first loop made.	**Step 4:** Pull.

Figure 19.6: Tying the Eight-Knot

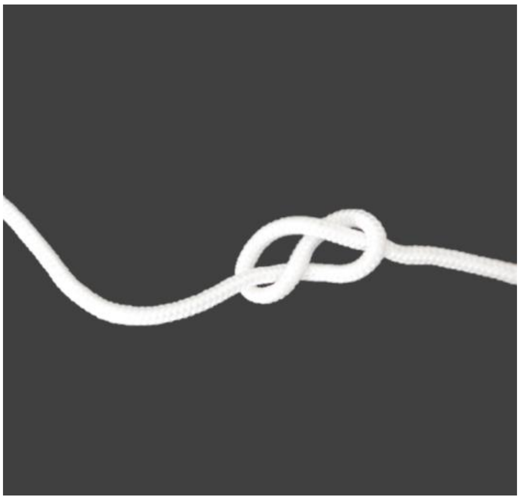


Figure 2.7: The Eight-Knot

2.1.2 The Combined Knots

The following combinations of knots were selected for this research. The knots were evaluated according to workability, size, maximum strength and ability to keep the initial tension. The combinations are coded with colors, which will continue throughout the report.

Combination 0 (Figure 2.8) consists of the turnbuckle, fixed by an Eight-Knot on each side. The turnbuckle serves as the reference in future tests.

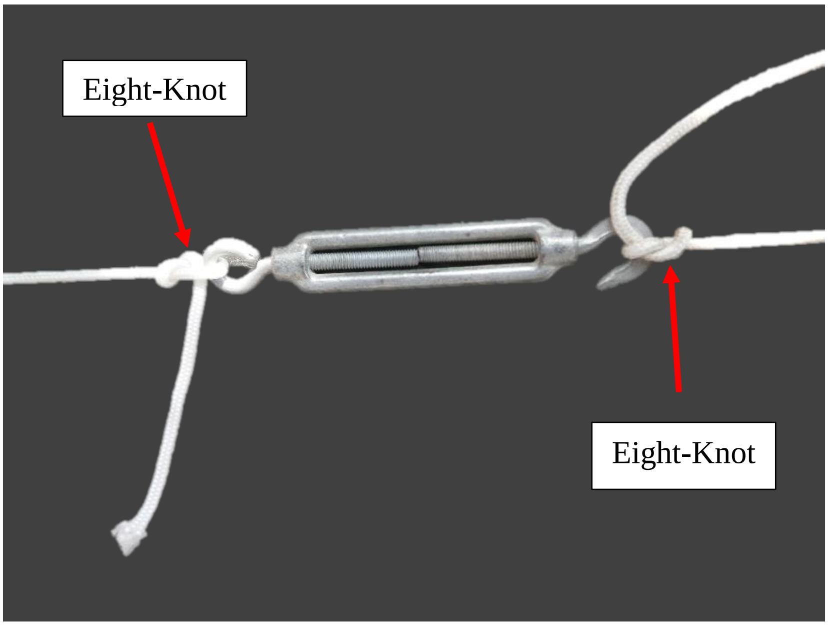
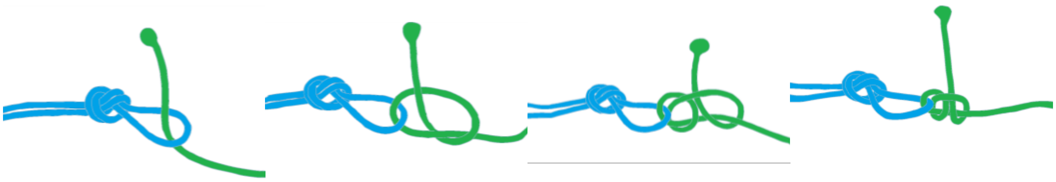


Figure 2.8: The Turnbuckle

Combination 1 (Figure 2.9-2.10) is called the Horse-Tie as it long has been used in Cusco to tie horses. The combination is comprised of an Overhand

Loop at one end, a long tail to tension the rope and finally the double Half Hitch serving as a stop.



Step 1: Make an Overhand Loop and put the active string through.

Step 2: Make a Half Hitch

Step 3: Make the second Half Hitch

Step 6: Pull tight.

Figure 2.9: Tying the Horse-Tie

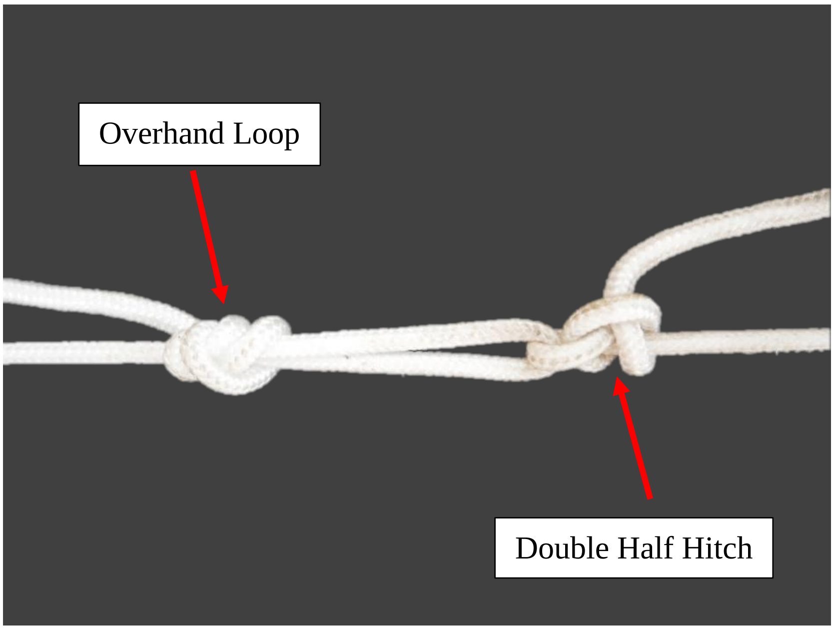
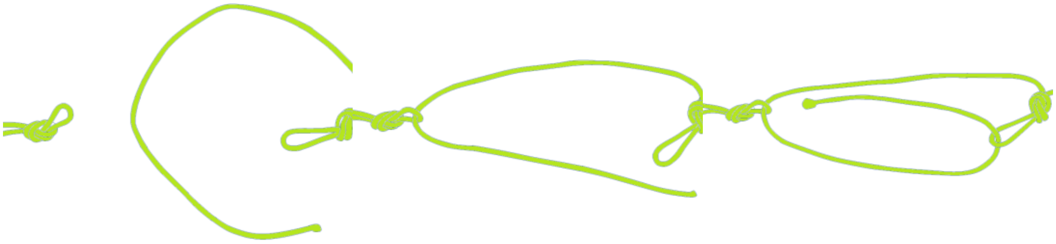


Figure 2.10: The Horse-Tie

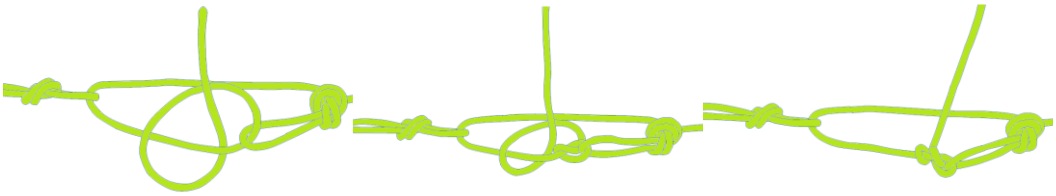
Combination 2 (Figure 2.11-2.12), named the Pulley-Gear, is initially the same as previous. The difference is that another loop is applied, in order to increase the magnitude of force. The mechanism can be described similar to a pulley. This knot is based on two Overhand Loops, one with a big tail that serve for the tensioning act. The tail will pass through both buckle loops in order to ease the tensioning part. Next step is to pull the tail to win force and finally close the combination by two half hitches knot.



Step 1: Make two Overhand Loops, one at each end of the rope. Make sure one of the knots has a long tail.

Step 2: Put the tail throught the other Overhand Loop.

Step 3: Put the tail throught its own Overhand loop.



Step 4: Pull tight and close by making a first Hitch Knot

Step 5: Make the second Hitch Knot to ensure the closure.

Step 7: Pull tight.

Figure 2.11: Tying the Pulley-Gear

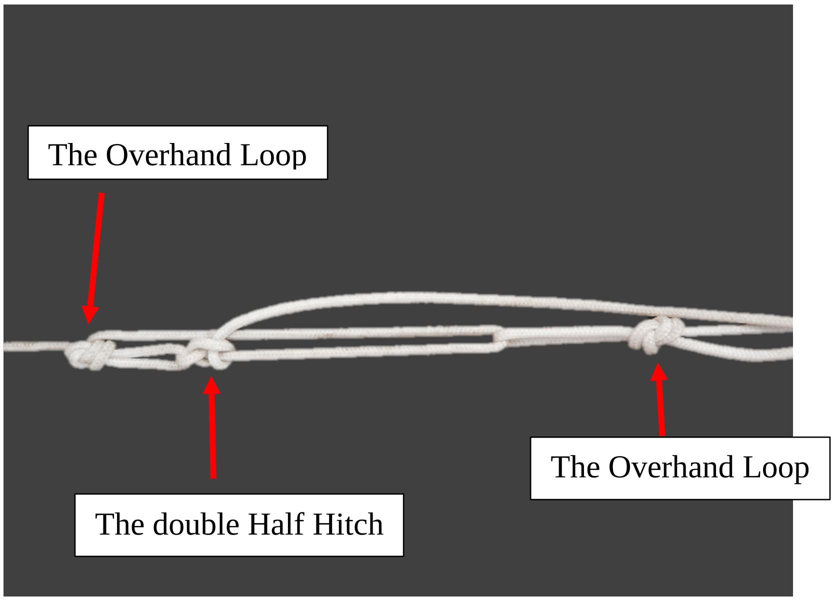
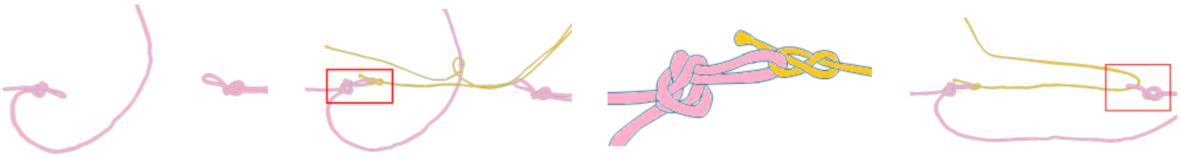


Figure 2.12: The Pulley-Gear

The steps of *combination 3* (Figure 2.13-2.14), the External Bond, is essentially the same as above except that it is an external rope that serves the tensioning. To be able to cut the external rope the tail of the loops has to be fixed. This are done by making an Eight-Knot at one of the tails and thereafter pull and tension the other tail through the eight loop. Finally the combination has to be fixed by a half hitch knot. The tail will then be pulled through an Eight-Knot and fixed by a half hitch.

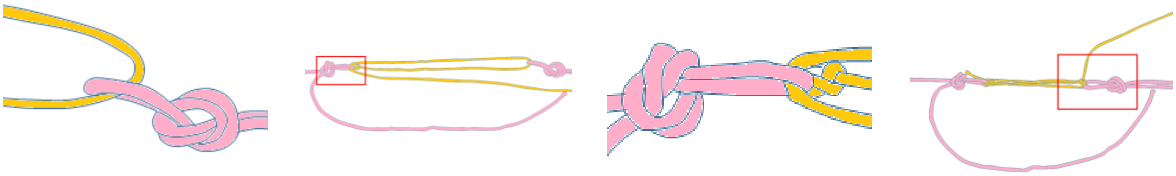


Step 1: Make a Overhand Loop at each end of the rope. Make sure that The Overhand Loops has a long tail.

Step 2: Fasten an external rope making an Eight-Knot at one of the Overhand Loops. See detail.

Detail: Step 3

Step 3: Pull the external rope through the opposite Buckle loop. See detail.

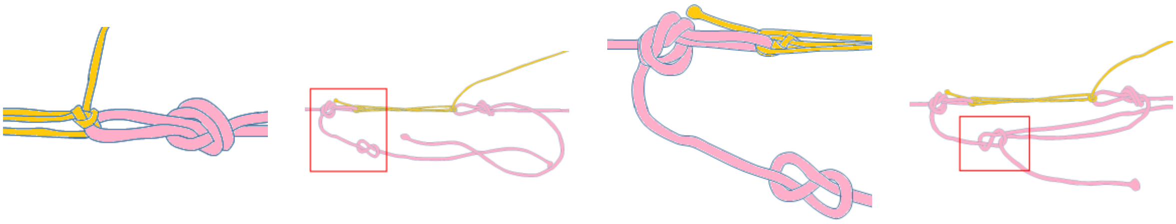


Detail: Step 3

Step 4: Pull the external rope through the Overhand Loop where it is fastened (where The Eight-Knot is).

Detail: Step 4

Step 5: Pull the external rope tight and close it by two Half Hitches.

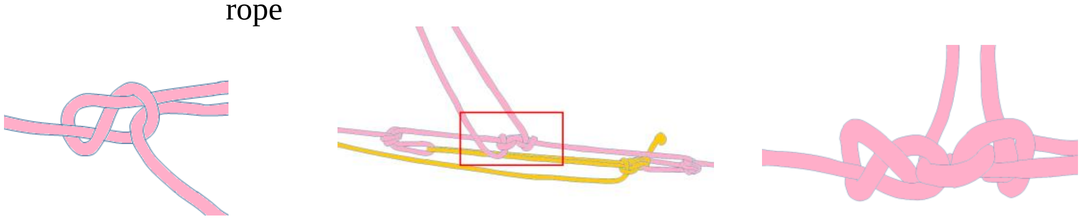


Detail: Step 5

Step 6: Make an Eight-Knot in one of the tails of initial rope

Detail: Step 6

Step 7: Pull the opposite tail through The Eight-Knot



Detail: Step 7

Step 8: Pull tight, and keep the tension closed by performing a double Half Hitch. As done, the external rope can be removed.

Detail: Step 8

Figure 2.13: Tying the External Bond

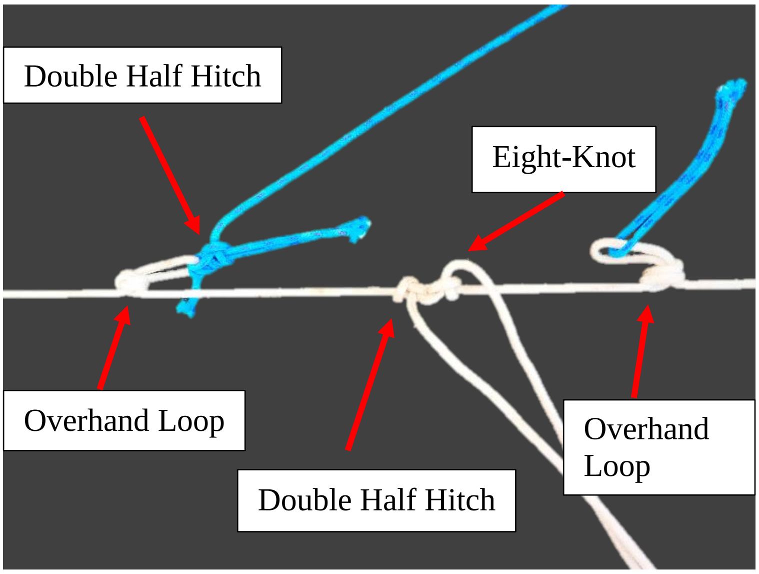


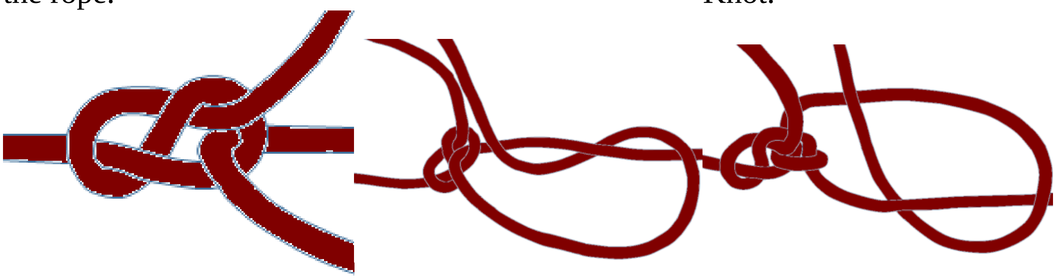
Figure 2.14: The External Bond. The blue rope shows the external rope, which after closing has been cut.

Combination 4 (Figure 2.15-2.16), the Taut-Guard, is a copy of the final steps above. An Eight-Knot is used, a tail pulled through and then fixed by a halt hitch. The Eight-Knot helps to strangle the rope as it is pulled through which is an advantage as the combination are being fixed.

Step 1: Make an Eight-Knot at one of the end of the rope.

Detail: Step 1

Step 2: Pull the other end through The Eight-Knot.



Detail: Step 2

Step 3: Pull tight, and keep tension by first making one Half Hitch Knot.

Step 4: Secure the tension to stay by performing a second Half Hitch Knot.

Figure 2.15: Tying the Taut-Guard

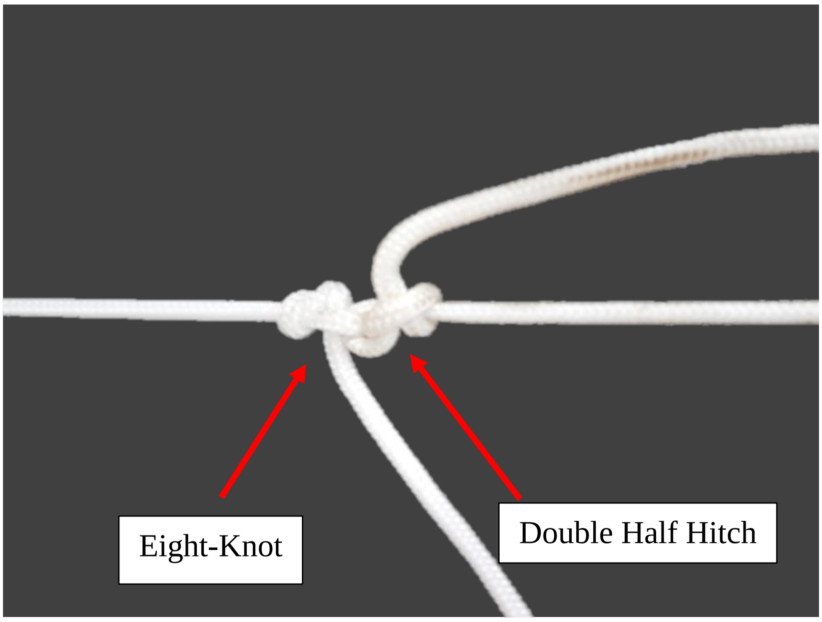


Figure 2.16: The Taut-Guard

The tests proceeded in three phases. The first phase included manual tests of initial tension and relaxation emphasizing the behavior of the combined basic knots. A second manual test was performed, in phase 2, including initial tensile test and relaxation of different dimensions of rope diameter. In both two first phases, the knot size was recorded. The last, and third phase, evaluated maximum tensile strength with covering both combination of knots and different dimension of diameter. Practical experience, photos, notes and visual observations were concluded throughout all three phases. To avoid the effect of perception, three researchers at PUCP perform the combinations individually and gave them a workability mark (high, medium, low).

Manual tensile experiments were designed and carried out in order to quantify the load that is possible to apply by a normal human when tensioning and tying ropes. The test also sought to determine the loss of in time relaxation (Figure 2.17).

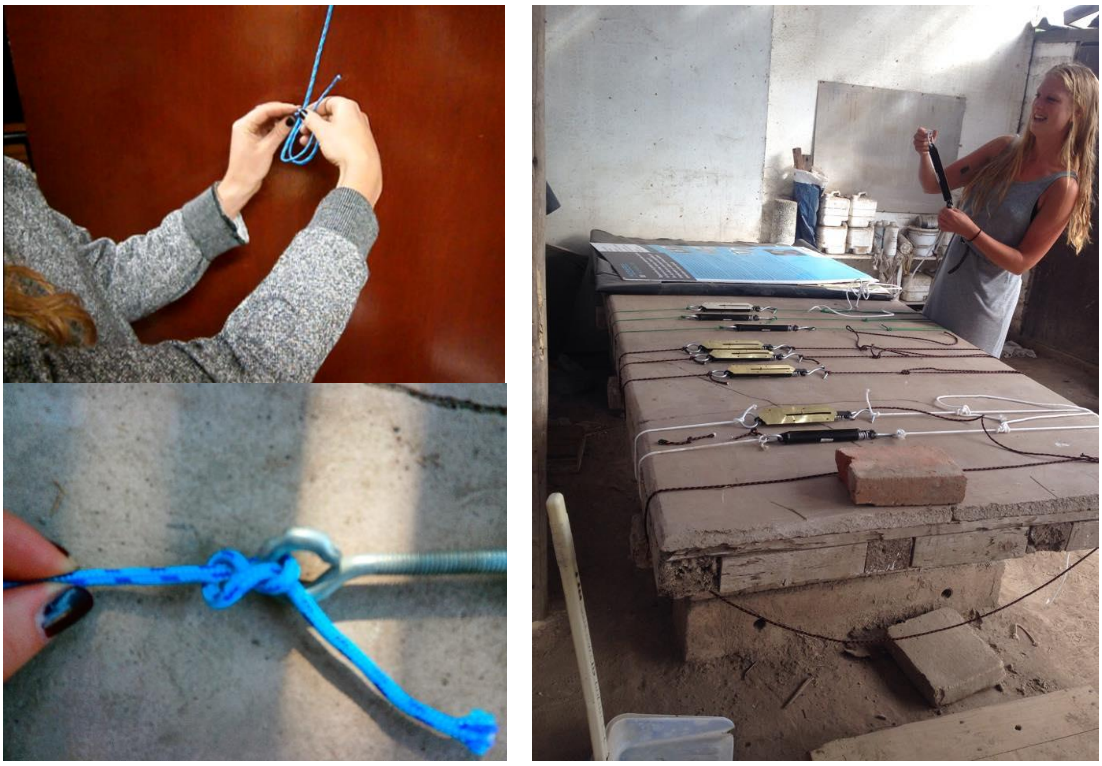


Figure 2.17: Working with the tests

The experiments were done at a temperature varying between 18-20 degrees Celsius (night and day temperatures in Lima in April) by manually tying each sample to a 1,25 meter wide table (which serves the purpose of simulating the boundary conditions of the adobe walls) (Figure 2.18).

Figure 2.18: Manualy test of initial tension and relaxation over time

The ropes were cut in half, and a dynamometer was attached to both ends by an Eight-Knot. The applied force was measured and recorded in kg-force with a Pocket Balance dynamometer (Figure 2.19) with a capacity up to 50 kg-force.

The value of the force was read from the dynamometer immediately as the roped were joined together. In this report the values are reported in newton.

In order to determine the relaxation in time, the starting force that the rope was subjected to was documented. A follow-up force measurement was carried out in a predefined period of time.

Figure 2.19: Pocket Balance Dynamometer

An *MTS (Material Testing System) universal testing machine* with a HBM (Hottinger Baldwin Messtechnik) load cell of 20 kN capacity was used to measure maximum tensile strength (Figure 2.20*Figure 2.20:* **The Universal Machine at PUCP**). Special top and bottom adapters were used to grip the samples, which were tied by a one Eight-Knot.

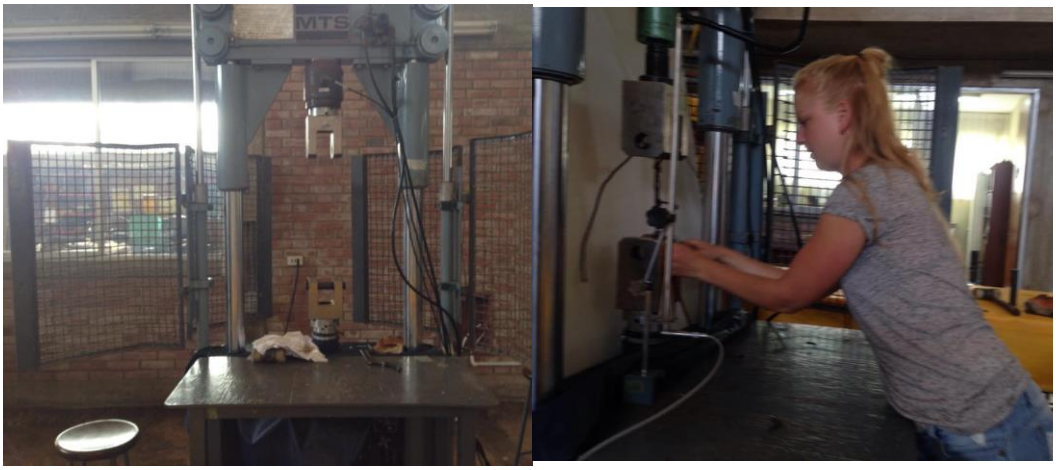


Figure 2.20: The Universal Machine at PUCP

To achieve long-term sustainability it is essential that the ropes are protected from anything that might damage or cut the internal or external fibers of the ropes. Even though Halyard ropes show good weather resistance properties (deMerchant, 2015), in a long term the ropes must be protected from exposure to UV and moisture. The plaster covering exterior and interior walls of adobe houses could serve this purpose. A layer of plaster is 20-30 mm thick (Sosa, 2015), which set the criteria for the knot sizes.

The sizes of the combined knots were determined with a simple measuring tape. Each knot was measured from table level up to highest point of the knots (Figure 2.21). The knots criteria for the knot sizes were marked accordingly Table *2.1*2.1.

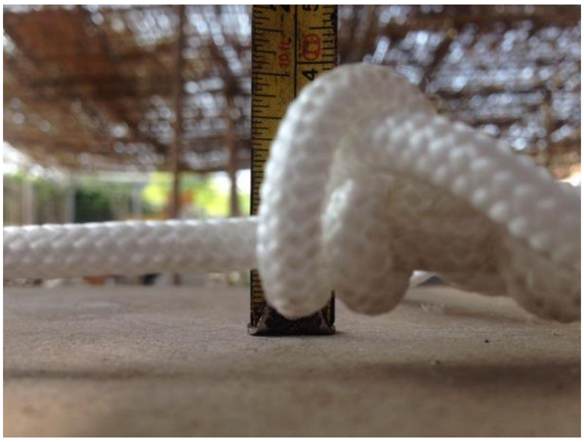


Figure 2.21: A knot measuring 4 cm from table to highest point.

Table 2.1: Criteria for the knot sizes.

Size [mm]	**Mark**
> 30	Inadequate
20-30	Acceptable
< 20	Adequate

Phase 1: Manual test of combinations of knots

Four knot combinations were tested, with three specimens for each configuration. Each specimen was prepared by a different person. The base specimen used was the turnbuckle. The rope diameter used was 3,97 mm (5/32”) for all specimens. Knot size was recorded. To record relaxation the force-data acquisition was performed following the sequence: 0 min, 15 min, 30 min, 60 min, and every 24 hours during a period of two weeks.

Configuration was defined by the type of knot combination. Table 2.2 explain and summarizes the four subjected combinations. To simplify the results, the combinations will be color coded in diagrams. The colors correspond to those in the instructions of the combinations, find in previous section of the report. Figure 2.22 show 4 configuration with 3 specimens in each beside the reference specimen of the turnbuckle.

Table 2.2: Definition of the combinations

Combination	N º of simple knots	Name	Color code
C0	2 Eight-Knot	Turnbuckle	Gray
C1	1 Overhand Loop 1 Double Half Hitch	Horse-Tie	Blue
C2	2 Overhand Loop 1 Double Half Hitch	Pulley-Gear	Green
C3	2 Overhand Loop 2 Double Half Hitch 1 Eight-Knot External Rope	External Bond	Yellow
C4	1 Double Half Hitch 1 Eight-Knot	Taut-Guard	Red

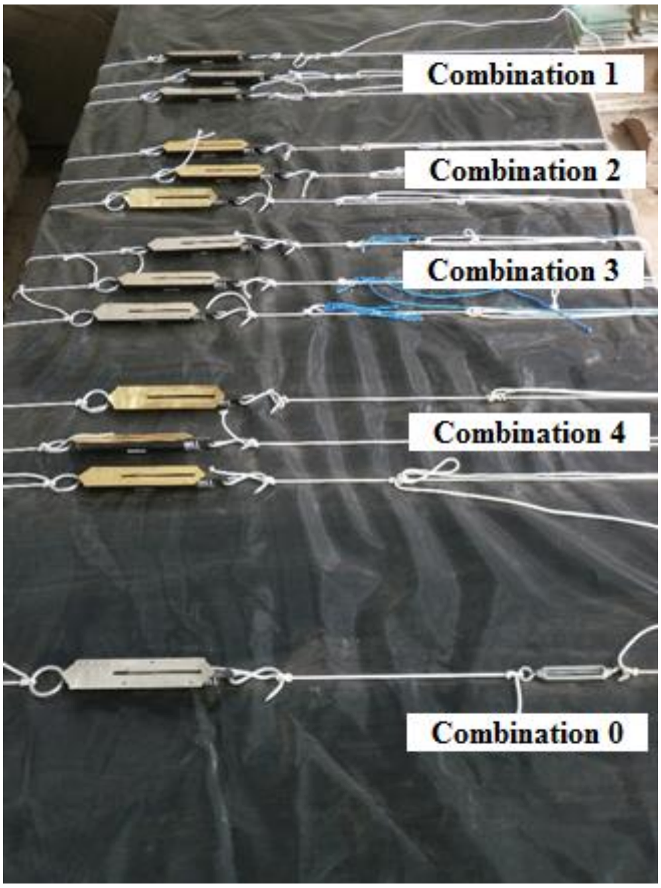


Figure 2.22: Combination 0, the reference specimen. Combination 1-4, three spicimens each configuration.

Phase 2: Manual test of rope diameters

The most workable type of knot was determined to be Combination 4 (The Taut-Guard). The same testing procedure as previous manual test was followed using ropes of different diameters. This was done in order to analyze the effect of the diameter of the rope on the tensile strength that the chosen type of knot could withstand. The value of the force was read from the dynamometers and documented according to the following time sequence: 0 min, 15 min, 30 min, 60 min, every 24 hours during one week, and every 48 hours during one week. The procedure included determination of knot size with similar performance as in previous measurements.

A set of three specimens were tested for each diameter, 3,175 mm (1/8”) 3,97 mm (5/32”) and 4,76 mm (3/16’’) (Figure *2.23*2.23), were prepared according to the previously described setup. Figure 20.24 shows the configuration of rope diameter, with three specimens of each size.

Figure 2.23: Rope diameters used in phase 2. From the left; 4,76 mm (3/16’’); 3,97 mm (5/32’’); 3,175 mm (1/8’’).

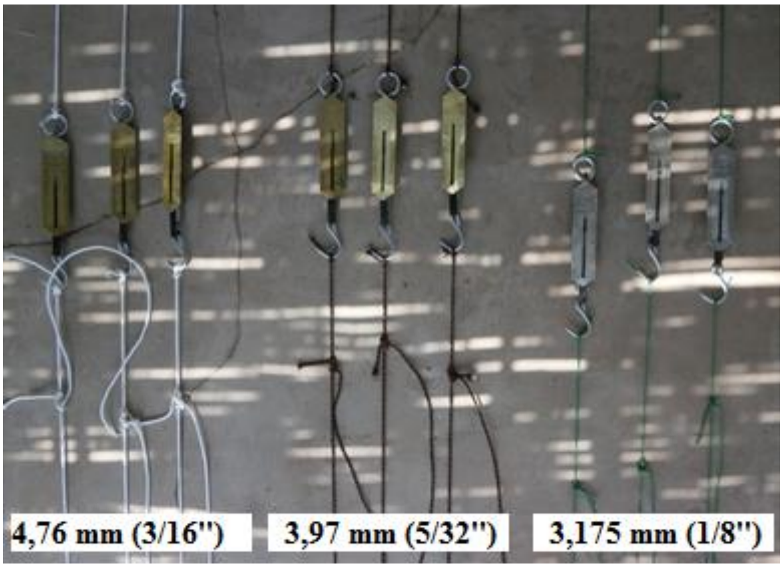


Figure 20.24: Three configurations with three specimens each configuration.

Phase 3: The MTS Universal Testing Machine

Figure2.25 shows a specimen of combination 4 between two adapters. The tests were performed on ropes with diameters of 3, 97 and 4, 76 mm. Three replications of the ropes without knots, and five combinations (combination 0-4) of knots were performed. This gives a total of 36 samples.

Before testing, the samples were prepared with knots. Then test was carried out by attaching the samples to the grips with an Eight-Knot. Before giving a load to the specimens, the distance between the grips was measured. A tensile force was then applied by the upper grip at a crosshead speed of 50 mm/min. The force and displacement values were measured every 0, 04 second, by an associated software.

Figure 2.25: A specimen placed between two grips. The specimen is fixed to the grips by Eight-Knots.

2.2 Portable shaking table demonstration tests

The shaking table is demonstration equipment designed to perform seismic simulation tests on small scale adobe houses. The objective with the device is to communicate the importance of seismic reinforcement and create awareness about seismic vulnerability and hazards (Blondet & Rubiños, 2013).

2.2.1 The portable shaking table

The portable shaking-table is 60x60 cm platform, fixed to a structure that resembles a bicycle, and is powered by a person by auctioning two pedals. The movement of the table is horizontal due to an eccentric mechanism based on a combination levers and pulleys. The eccentric gear (Figure 2.27) transmits a force that is transformed into a constant horizontal.**Fel! Hittar inte referenskälla.** The reduced model weight of the device is 90 kilograms. Figure 2.26 shows the bicycle and Table 2.3 enumerates more features.

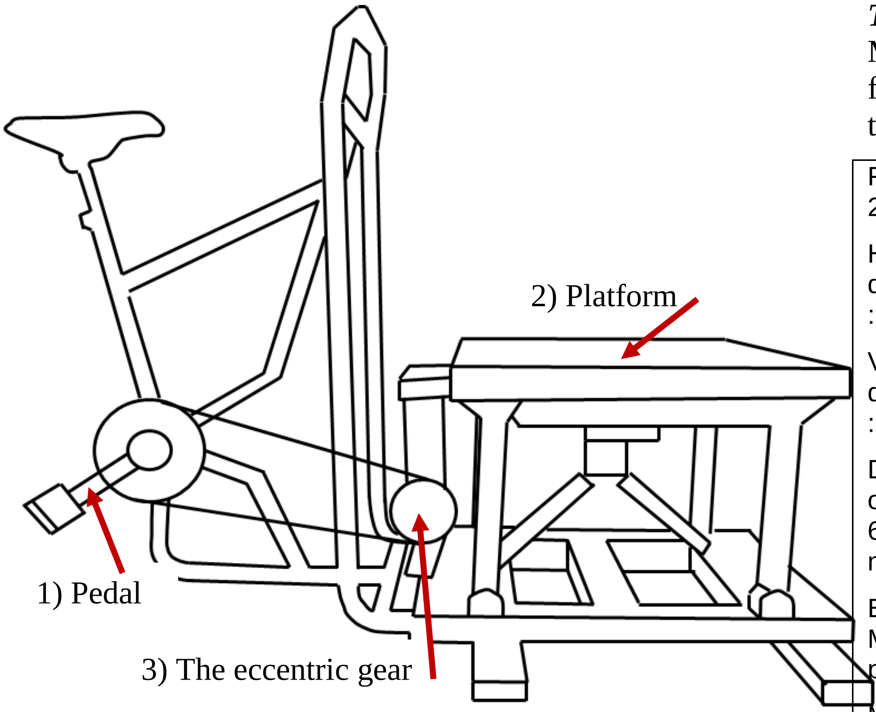


***Figure 2.26*: The Portable Shaking-Table**

Table 2.3: Main features of the device

Frequency: 2-5 Hz
Horizontal displacement : 50 mm
Vertical displacement : 15 mm
Dimensions of platform: 600 x 600 mm
Energy: Man-powered
Mechanical system: Similar to a bicycle
Shape: Ergonomic
Material: Aluminum structural
Reduced model weight: 80 kg

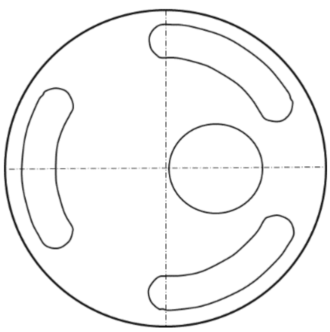


Figure 2.27: Section of the eccentric gear

The technical requirements of the device were specified by a project group at PUCP designed by Jorge Alencastre, the mechanical engineer of the team to be used as an in-situ demonstrations mean (Blondet & Rubiños, 2010). It is a main tool for the application and, hopefully, acceptance of the developments investigated in this project, which are in fact the main goals. The intention is to demonstrate in-situ and in-vivo the difference that the tensioning ropes make on the adobe houses the people live in when an earthquake occurs.

Subjecting scale-replica of traditional adobe houses to earthquake-like actions is the objective of the demonstrations. For that purpose, adobe models need to be manufactured. At this stage, three 1:10 scale adobe models were manufactured, two reinforced with tensioning ropes, and one without reinforcement. The latter being a reflection of the houses that are currently being used in the village of Pullo, Peru.

Due to the dimensions of the scaled models, 240x400x190 mm^3, with an average weight of 15 kg some modifications had to be added to the shaking-table device (Figure 2.28*:* **The**). Among such alterations, a removable wooden platform was included to the existing table. Dimensions of the new table were 1300x600x18 mm^3. The mounting of the new table was done using existing boreholes for the attachment by 7 screws, 12 mm in diameter.

Figure 2.28: The new 1300x600x18 mm^3
shaking platform

2.2.1 Making small adobe bricks

A total of 1500 adobe bricks with dimensions of 40x40x10 mm^3 and 300 adobe bricks with dimensions of 40x20x10 mm^3 were shaped. The material used to fabricate the bricks is the same as that used for the construction of the full scale models, which was soil, straw and sand, in a ratio of 5: 1: ¾ (Blondet, Vargas, Sosa, & Soto, 2014). The composition differed from the full scale model (ratio: 5:1:1) due to the small dimensions of the model bricks (Herrera, 2009). The bricks had a density of 0,1875g/cm^3.

Clean and organic free soil (soil for cultivation, locally known as *tierra de chacra)* was mixed with water to get mud. Different tests (dry strength test, roll tests), explained by Blondet et.al (2011), were done to determine good mud properties. The mud must sleep for at least two days to improve the integration and distribution of water with clay particles, then fine cut straw (maximum 1 cm in lengths to prevent cracking) can be added. The composition of mud and straw were then mixed and knead well in a blender (Figure 2.29*:* **A blender used to mix mud with straw**). Molds with required size, dipped in water and then sprinkled with fine sand to prevent the bricks to get stuck, were filled. A scraper was used to even the faces. The molds were emptied at a drying area; shadowed, non-windy and free from grass or rocks. Due to the small size of the bricks, they only had to dry for three days (normal size bricks should dry for a week). The tutorial made by Blondet et.al (2011), includes an accurate description on how to make adobe bricks. Photographs depicting the manufacturing process are found in Figure 2.29-2.31.

Figure 2.29: A blender used to mix mud with straw

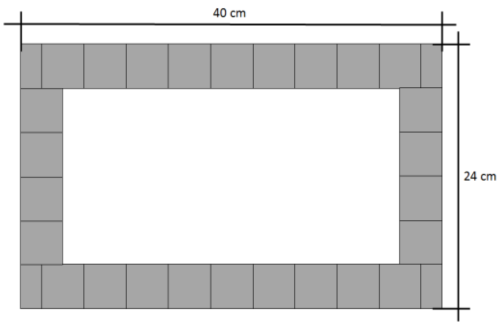
Figure 2.30: A clean and protected drying site.

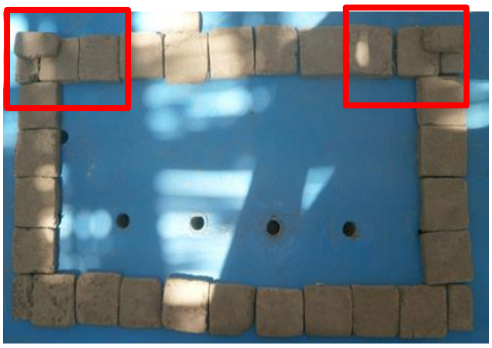
Figure 2.31: Molds for factoring of 40x40x10 mm^3 full-bricks, and 40x20x10 mm^3 half-bricks.

2.2.2 Building non-reinforced and reinforced small scale adobe houses

In despite of previous test s of small scale models, carried out by Marcial Blondet & Alvaro Rubiños (2013), contemporary were built without mortar. In this phase of the long-term project in Pullo, the aim was not educate the inhabitants on adequate building techniques, nevertheless to create seismic awareness. The exclusion of mortar decreased the preparing time of the models, which was found beneficial for an in-situ demonstration in Pullo.

The houses were built with bricks of the dimension 40x40x10 mm^3. A house size of 40x24 mm^2 was chosen for the models, and 10 respective 6 bricks were counted in each direction to accomplish requested dimensions. The houses were chosen a rectangular form to simulate typical planning in Pullo. Furthermore, the bricks were placed overlapping each other. This is a common building technique (Figure 2.32).





(a) (b)

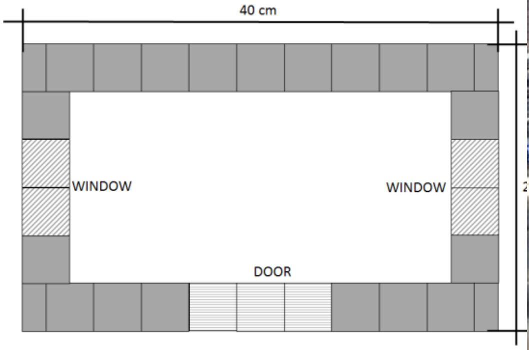
Figure 2.32: (a) A basement (b) how to start the second layer of bricks. The red marks show how the rows have to be alternated in order to create an overlap of the bricks.

Moreover, the improved models were reinforced with a system simulating reinforcement with nylon ropes. Even though the subjected system is not fully developed, it was thought of utmost importance to start implementing the idea.

Non-reinforced model

The non-reinforced model (Model 1) was built only using adobe model bricks, put in layers overlapping each other. One long side included a door. A window was constructed in both short side wall. The lintels of the openings consisted of thin wooden slats similar in width as the abode bricks. A light 1 mm thin balsa sheet (*Ochroma lagopus*) with density of 0.16 g/cm^3 covered the bricks to simulate a roof. A cellulose-based glue (A fast-drying, lightweight glue, often used by architects for wood modeling) was used to glue the coverage to the bricks.

Figure 2.33 shows the construction of the model including how the bricks overlap. One long side included a door. A window was constructed in both short side walls. The lintels of the openings consisted of thin wooden slats similar in width as the abode bricks. Table 2.4 summarizes the characteristics.



(a) The basic planning of the model

(b) Bricklaying that overlaps, creating joints

(c) The house progess

(d) The house progress

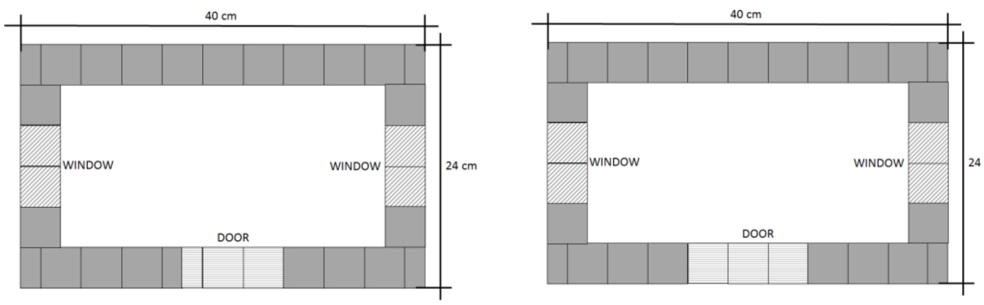
Figure 2.33: Construction of the non-reinforced house model

Table 2.4: Characteristics of the non-reinforced adobe house model

Width	240 mm.
Length	400 mm
Height	190 mm
Weight	13, 5 kg
Stores	1
Amount of model bricks	350 full bricks 120 half bricks
Reinforcement: Vertical	Yes. Every column of bricks were reinforced vertically.
Reinforcement: Horizontal	Yes. Every second row were reinforced horizontally.
Wall	Bricks overlap
Collar beam	Yes
Roof	Flat roof
Windows	Two. Centered in the short walls. 80x80mm^2 Window height above table: 90mm
Door	One. Centered in backside walls. 120x150mm^2.

Reinforced adobe models

Two reinforced models (Model 2 and Model 3) were built with the same basic technique as the non-reinforced. One long-side included a door. A window was constructed in respective short-side wall. The lintels of the openings consisted of thin wooden slats similar in width as the abode bricks. The two models featured minor differences in their planning; the door dimension of model 3 were increased with a half brick in order to create symmetry (Figure 2.34).



(a) (b)

Figure 2.34: The difference in door dimension. (a) Model 2. (b) Model 3.

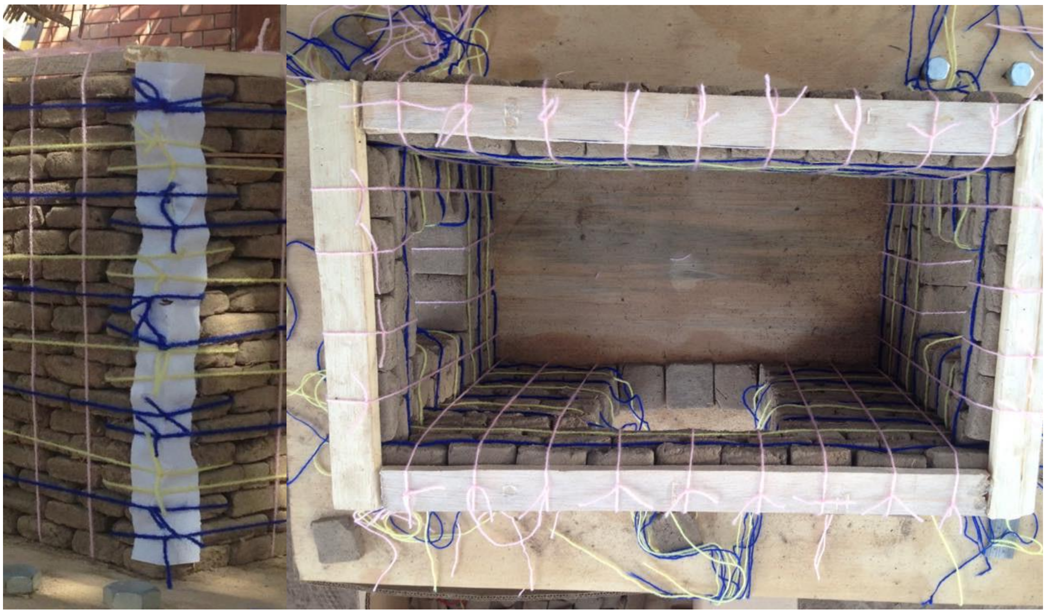
The models were reinforced vertically and horizontally with yarn *(Lana Escolar*), 1 mm in diameter to simulate the reinforcement system of ropes

(Figure 2.35a). The yarn was tensed and tied (no specific type of knot) after all the bricks were laid (Figure 2.35b). The vertical reinforcement was tied around the collar beam (Figure 2.35d), which serves the purpose to connect the walls and prevent separation when put under earthquake forces. A lightweight material constituted by balsa wood (*Ochroma pyramidale*), with a density of 0.16 g/cm^3 was used on top of the walls to simulate the collar beam (Figure 2.35d). Paper was placed outside the corners of the walls, and the horizontal reinforcement was tied around them (Figure 2.35c). The purpose of this was to prevent that the yarn from sliding between the bricks and therefore lose tension.

Another difference between the models were use of crossties. In the first model crossties were implemented to stabilize the walls, nevertheless it was found not making a great impact in testing. Moreover, the crossties were difficult and time consuming to preform considering the small scales of the models.

(a) Vertical (pink strings) and horizontal reinforcement (blue string)

(b) The yarn was left hanging until the bricklaying was finished.



(c) Paper put on corners (d) The yarn were tied around a collar beam

Figure 2.35: Description of the method to reinforce the models.

The roof support (Figure 2.36) was made of a network of 4x4 mm balsa wood, which was then covered with a light, 1 mm thin balsa sheets for aesthetic purposes. Cellulose-based glue was used to bond the parts of the roof (collar beam, roof support and the sheet)

Figure 2.36: Structure of the roof support made of balsa wood.

To improve wall stability and prevent brick-separation at upper parts of the walls, the roof slope of the first model were flattened in sequential tests (Figure ***2.37*** 2.37). Figure 2.38 show the finished models, and Table 2.5**: Characteristics of two reinforced adobe house models (Model 2 and 3)** enumerates in detail the characteristics of the Model 2 and 3.

(a) Lent to roof (b) Flat roof

Figure 2.37: Differences in roof appearance

(a) Model 2 (b) Model 3

Figure 2.38: The fronts of the reinforced models

Table 2.5: Characteristics of two reinforced adobe house models (Model 2 and 3)

Characteristics	Model 2	Model 3
Width	240 mm.	240 mm.
Length	400 mm	400 mm
Height	Tall wall: 230 mm Short wall: 190 mm	190 mm
Weight	16,5 kg	13,5 kg
Stores	1	1
Amount of model bricks	440 full bricks 120 half bricks	350 full bricks 120 half bricks
Reinforcement: Vertical	Yes. Every column of bricks were reinforced vertically. Crossties were installed through each wall 12 times.	Yes. Every column of bricks were reinforced vertically.
Reinforcement: Horizontal	Yes. Every second row were reinforced horizontally.	Yes. Every second row were reinforced horizontally.
Wall	Bricks overlap	Bricks overlap
Collar beam	Yes. Circumference: ~ 40x40 mm^2. Cross-section: 30x10 mm^2.	Yes. Circumference: ~ 40x40 mm^2. Cross-section: 30x10 mm^2.
Roof	Lean-to roof. Slope range of 1:6.	Flat roof
Windows	Two. $80x80mm^2$ Window height above table: 90mm	Two. $80x80mm^2$ Window height above table: 90mm
Door	One. 100x150 mm^2	One. 120x150 mm^2

2.2.2 Dynamic testing of the adobe houses

To test the behavior of the manufactured adobe houses, when applying dynamic shaking, they were placed on the shaking-table device. The test was performed on one single model (Figure 2.39), and on two simultaneous scaled houses and (Figure 2.40). The forces were applied by pedaling on the bicycle-like device. The latter test was found really efficient, as the non-reinforced collapsed immediately however the reinforced withstand great amount of pedaling. This was a preliminary test before bringing both the device and small scale models to the district of Pullo, and making the demonstration in front of the people. The latter one, with two parallel houses will be performed in Pullo to show how successful reinforcement can protect a house structure.

Figure 2.39: First test with a single reinforced model

Figure 2.40: Second test with two parallel models.

2.3 Situational evaluation and raising the seismic awareness

To continue the long term project, a second visit to Pullo was planned and executed. In order to meet the specific and complex reality of Pullo, an interdisciplinary team was assembled. The team consisted of three engineers, a psychologist and a communicator (Table 2.6 and Figure 2.41).

Table 2.6: Members of the interdisciplinary team

Name	**Career**
Maria Teresa Rodriguez Campos	Psychologist
Snowy Janet Ruth Chavez	Communicator
Álvaro César Montenegro Runiños	Civil Engineer
Malena Alessandra Serrano Lazo	Civil Engineer
Elin Mattsson	Construction Engineer

Figure 2.41: From the left; Álvaro, Elin, Maria Teresa, Ruth and Malena

In order to reach Pullo, the travel route was planned according to Table 7 and Figure 2.42:

Table 7: Travel route to Lima-Pullo

Date	**Route**	**Time**	**Transport**
Thursday 21/5	Lima - Nasca	P6.40 AM - 15 PM	Bus
	Nasca - Acarí	17 PM - 19.30 PM	Caritas Caravelí
Friday 22/5	Acarí - Pullo	6 AM – 12 AM	Caritas Caravelí

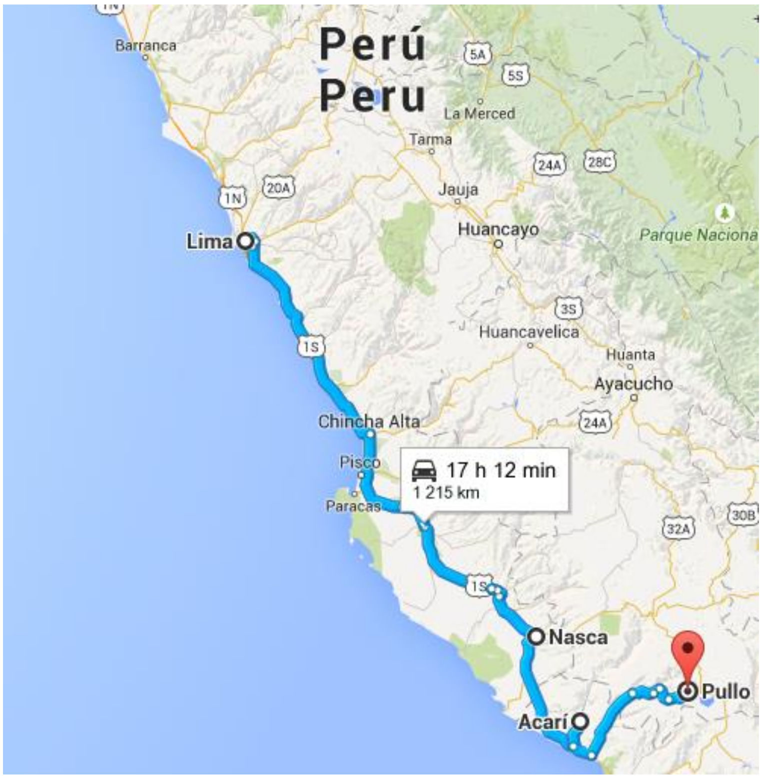


Figure 2.42: Travel route Lima-Nasca-Acarí-Pullo
(Google , 2015)

The transportation of the shaking table and the adobe pieces was arranged beforehand with a logistic company. The device (with a weight of approximately 90 kilograms) was transported from the laboratory in a car with a hatchback body type. Approximately 1000 pieces of adobe bricks each of 40x40x10 mm^3 in size, and 400 of 40x20x10 mm^3 in dimension, with a total weight of 45 kilos, were packaged and sent. Figure *2.43*2.43 shows the procedure of the transportation.

Figure 2.43: Transportation of the shaking table and adobe bricks

The mutual objective for the interdisciplinary team was to transfer information on the situational diagnosis to municipal authorities and residents. The psychologist and communicator planned inquires at municipal level on the subject of risk management. The aim was to evaluate the willingness of participation on an interdisciplinary course on disaster risk management.

For the engineers the overall objective was to raise the seismic awareness and create understanding of the importance of improved house structures. This part involved a presentation with the portable shaking table as headline. It also aimed to implement the idea of reinforcing with ropes. Furthermore, the visit thought to make an investigation of the infrastructure (materials sold in the area, seismic damages on buildings, typical building techniques etc.) in order to present proper planning for continue phases of the long term project.

The activities of the trip were planned pursuant to the schedule shown in Table 2.8.

Table 2.8: Schedule of visit in Pullo

Thursday 21/5	**Friday 22/5**	**Saturday 23/5**	**Sunday 24/5**	**Monday 25/5**
Travel	Travel Building the reinforced house model	Investigation of house structures in Pullo and the surrounding annexes	Building the unreinforced model. Presentation targeting the authorities of Pullo Travel	Travel

The presentation aimed to convince the inhabitants of Pullo on the importance of the suggested training project. Besides educational contents, it sought to show social elements such as the impact of being agent of your own life.

The performance was planned to commence with a presentation of the agreements between PUCP and Caritas Caravelí, along with the objectives of the visit. Thereafter the engineers would present the diagnosis assessed during the visit followed by a demonstration aiming to raise awareness and understanding of the vulnerabilities in the contemporary situation. Finally, the psychologist and communicator thought to explain the purpose of the proposed risk management course.

Subsequent sections will describe the procedure to evaluate the current building situation followed by the methodology used to raise the seismic awareness.

2.3.2 Evaluation of the current building situation

In order to select vulnerable buildings that could be subject for reinforcement in later phase of the project, a visual research objected to identify the quantity of diverse house structures. The survey buildings were evaluated according site condition, construction technique and quality. Good soil properties were determined by performance of a drying strength test. The test, described by Marcial Blondet et al. (2011), consists of making a minimum of 5 mud balls, (20 mm in diameter), letting them dry for 24 hours. If the soil properties are adequate, the mud balls cannot be crushed by hand after the drying time.

The earthquake destruction pattern of (from the earthquake in 2014) was recognized and summarized. Visual observations, in-situ documentation and photos contributed throughout the investigation. Interviews with the inhabitants were done in order to identify available materials, building history, adobe making process, thoughts about construction, earthquake fear and seismic consciousness. In subjecting a building for a future reconstruction program the demands of the inhabitants had to meet the employment opportunities at PUCP and size of the project. The survey sheets used in field can be found in Appendix B.

2.3.1 Raising the seismic awareness

The methodology of the presentation was to alternate videos (produced at PUCP in previous researches) and questionnaires in order to interact and guide the audience to the conclusion that the seismic reinforcement is necessary. An overall willingness to participate on the training program was objected. As a highlight and end of the presentation, the portable device was planned to be exhibited. The presentation was planned according to Table 2.9:

Table 2.9: Methodology of the presentation

Video	**Objective**	**Follow-up question**	**Time**
Huaraz earthquake video (1970)	Through engineer research it is determined that people in time forget the horror of earthquakes (Serrano, 2015). This video aim to get the attention of the audience and to remind upon horrors of an earthquake.	Do you think people had time to get out of their homed when the earthquake occurred?	1 min
Geogrid motivational video	The video was recorded in a project similar to the presented. Aim is to show that other people accepted help and built their own nice, sustainable houses. Show that it is important to accept the training program.	Did you see when the cracks occurred on you house in the earthquake last year?	5 min
A video of a laboratory testing of an unreinforced module.	To emphasize that you cannot see when cracks occurs in an unreinforced house as it collapse without notice.	Do you think it is important to have safe houses?	1 min
A video of a laboratory testing of a module reinforced with nylon ropes.	To show that reinforcement with nylon ropes is effective and get them interested on learning it.	Do you know how to build a safe house as in the video?	2 min
Demonstration of the portable shaking table and small scale house models.	To give the presentation a fun approach in bringing the laboratory to field. It also aims to avoid skepticism and interact the people.	Do you think the ropes can help you? Who wants to participate on this purposed training project?	10 min

Additionally to the presentation a figurative resume of the project was posted on walls. This was in order to promote the cooperation between the community, PUCP and Caritas Caravelí and give a very positive angle of incidence. The posters can be found in Appendix C.

3 Results and discussion

3.1 Tensioning knots

The purpose of this investigation was to find out if a knot can replace the turnbuckle in order to economically efficiency a reinforcement system of ropes. Four combinations of knots were studied and compared with the turnbuckle. Additionally, the impact of rope diameters was evaluated. Results from various tensile test will be brought together and discussed.

Carlos Sosa (2015) stated that a full scale house need around 200 turnbuckles, which indicates that including them , is a time consuming task that could be reduced. Considering the amount, few steps in implementation of the combined knots would decrease the total time of reinforcing a house. If employing the reinforcement system, this could also come to see beneficial outcomes when it comes to expensive labors. Finally, knotting and tensioning a large number of ropes drain on hands and therefor an easy workability are rather important.

Practical experiences of the knots showed that Combination 1-3 (Horse-Tie, Pulley-Gear and External Bond) did not possess beneficial features in workability. Combination 1-2 had difficulties in retaining tense while closing the tie. Combination 3 contained a total of 6 knots including all the three different basic knots and additionally an external rope that had to be added and then removed. According to this, the procedure were time consuming and difficult in implementation.

Combination 4 (The Taut-Guard, Figure 3.1) on the other hand, consists of only two knots which leads to an easy implementation and a fast performance. Furthermore, the configuration was found having a feature that helps maintaining tension which provide a gentle closure (tying).

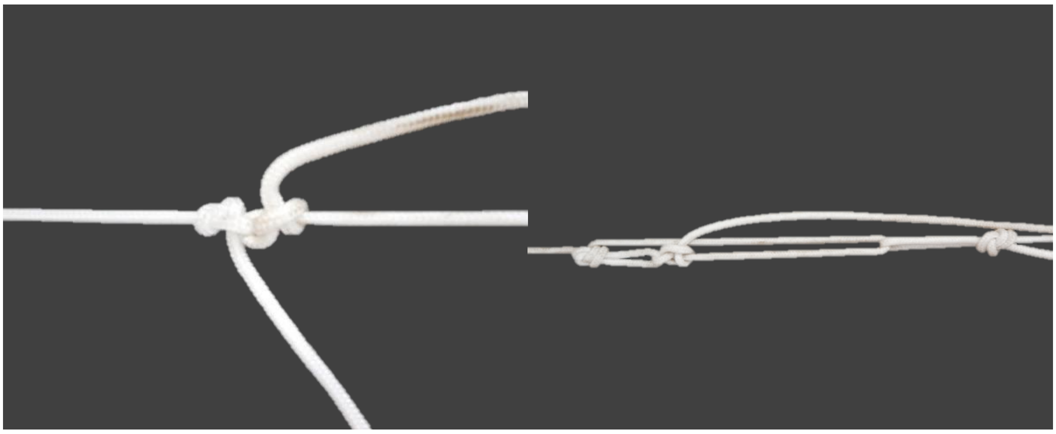


Figure 3.1: To the left: Combination 4 (Taut-Guard). To the right: Combination 2 (Pulley-Gear)

From testing of initial tension and relaxation of the different combinations, three diagrams, Figure 3.2-3.4, are presented. The first figure shows the diversion of three different test performers and the associated Table3.1 show their mean values. The two latter show mean values of three performed samples.

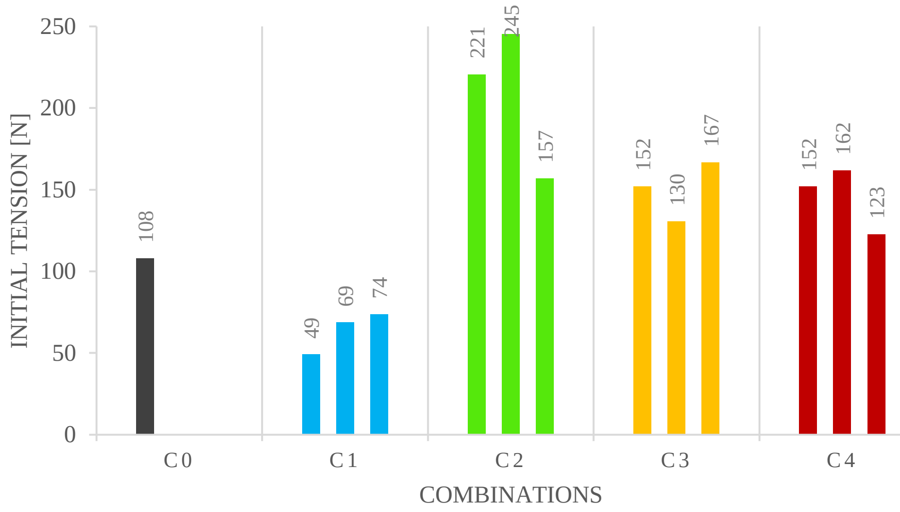


Table 3.1: Mean values [N]

C1	64
C2	208
C3	150
C4	145

Figure 3.2: Initial tension managed to pull while performing the combinations.

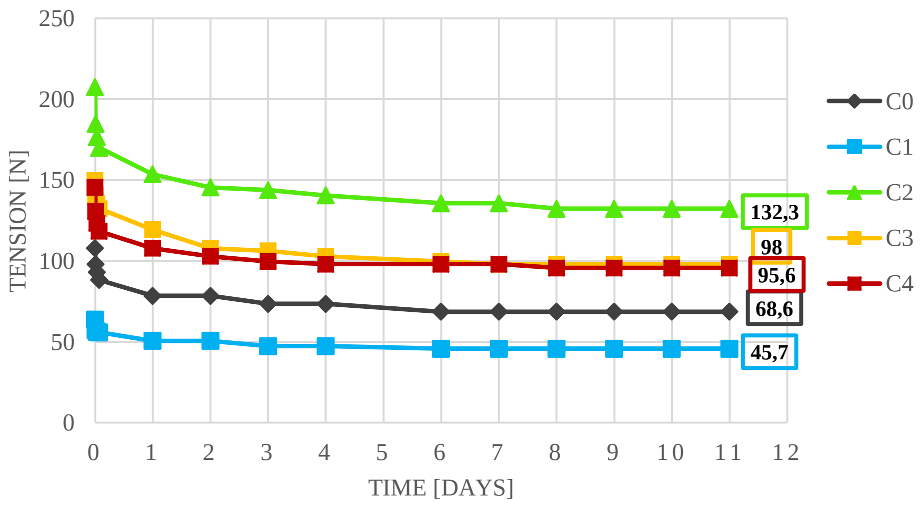


Figure 3.3: Reduction of tension over time of configurations of combination 0 to 4. The curves symbolize mean values of three samples.

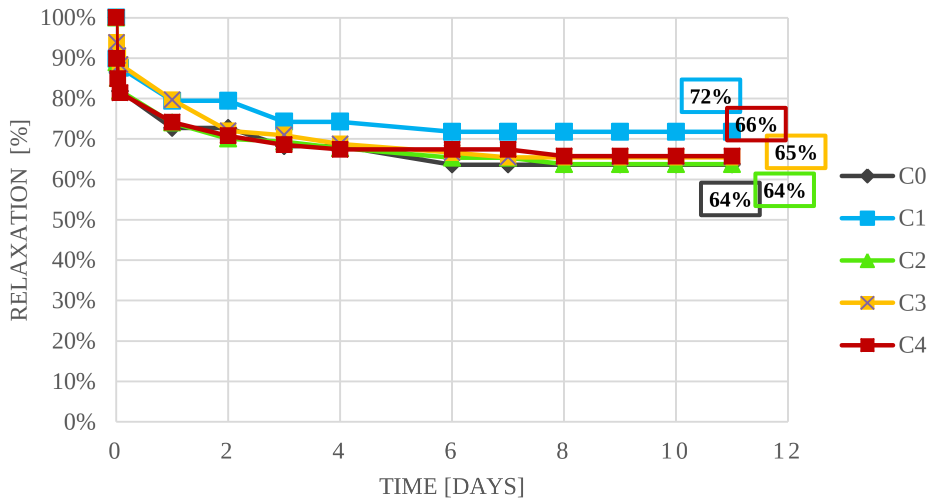


Figure 3.4: Relaxation in percent over time of configurations of combination 0 to 4. The curves symbolize mean values of three samples.

The columns in Figure 3.2 show that the performance of the subjected combinations various in term of initial tension. This is thought to be a consequence of the combination´s workability. Combination 2 (Pulley-Gear), which in despite of a difficult closure, gives the most initial tensile can be explained by a simple machines theory. The employment of two loops serve as a pulley and the mechanism increases the magnitude the force.

Majority of the combined knots overrun the value of the turnbuckle. On the other hand, only combination 2 (Pulley-Gear) exceeded the 200 N limit. The fact that the turnbuckle reached just above 50 % of the estimated, indicates that previous or present result are invalid. A reason for that could be that the turnbuckle were on tested in a single sample which implies contemporary results of the subject to be doubtful. Still, it underscores that the combinations cannot be compared to the value Marcial Blondet et al. (2014) projected. However, a mutual comparison of the knots is valid. By choosing combinations with easy workability or great features in gaining strength, a higher initial force can be performed.

The relaxation were found to follow a pattern with a rapid decrease initially and a stabilization after a week (6-8 days). An overall maintained force of 65 %, indicates that usage of different combinations does not affect the expected relaxation.

To find out the impact of rope diameter, an additional test was performed. All samples were accomplished with combination 4 (Taut-Guard). Results of the new tests are shown in Figure *3.5*3.5-3.7, and Table 3.2.

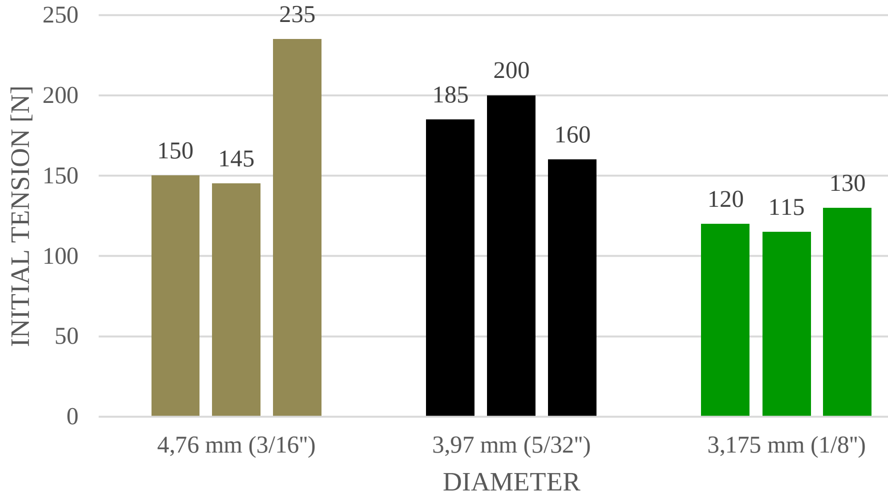


Table 3.2: Mean values [N]	
4,76 mm	173
3,97 mm	178
3,175 mm	119

Figure 3.5: Initial tension managed to pull with different diameters

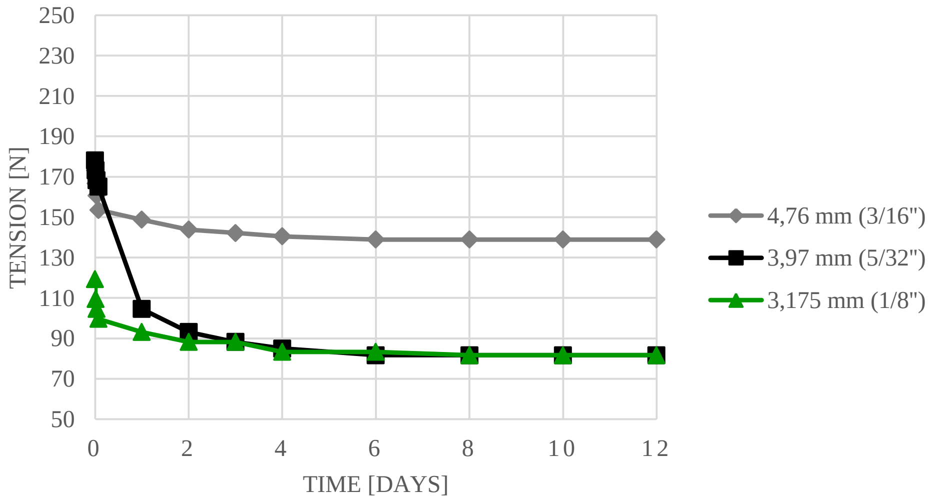


Figure 3.6: Reduction of tension over time. Configurations of combination 4 performed with different rope diameters. The curves symbolize mean values of three samples.

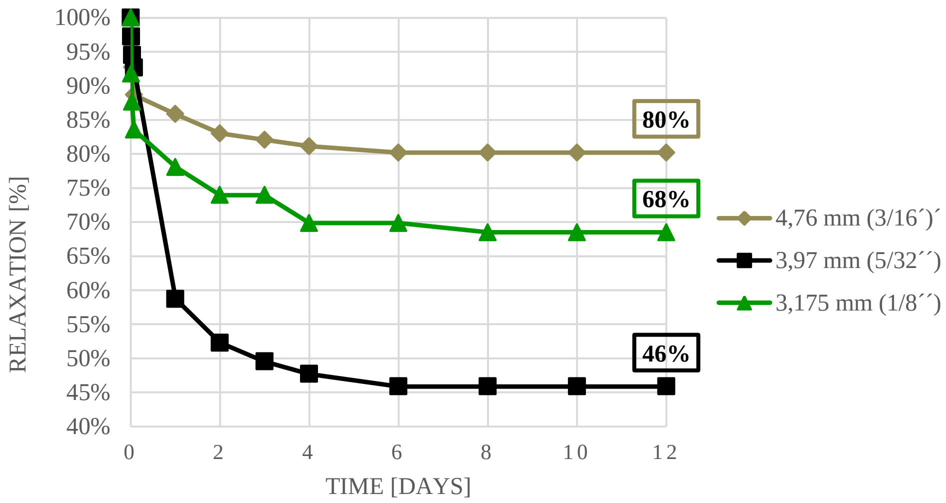


Figure 3.7: Relaxation in percent over time. Configurations of combination 4 performed with different rope diameters. The curves symbolize mean values of three samples.

In accordance to the primer test, all rope diameters reach a stability after 6-8 days. On the other hand, no pattern between rope diameter and force were found. Noticeable is the rapid loss of force that the 3,97 mm (5/32'') rope is subject for, which doesn't correspond to the other templates. In evaluation it is also found that there was a deviation of 20% between the performances of combination 4 (Taut-Guard) showed in Figure3.4 and Figure *3.7*3.7.

Maximum tensile strengths tests were subjected to further comparison of the different combinations. Moreover, the impact a knot has on a ropes strength was analyzed. Finally, characteristics of different rope diameter were subjected to observations. All four combinations including the turnbuckle were tested. And additionally a sample consisting only the rope.

During trials it was observed that the knots had to rearrange while being put under increased load. The breaking occurred suddenly and the force dropped to zero. Figure 3.8 shows a recorded curve at a typical test, where the rearrangements (the small dips in the curve) and the sudden break can be observed. Details of all curves can be found in Appendix A.

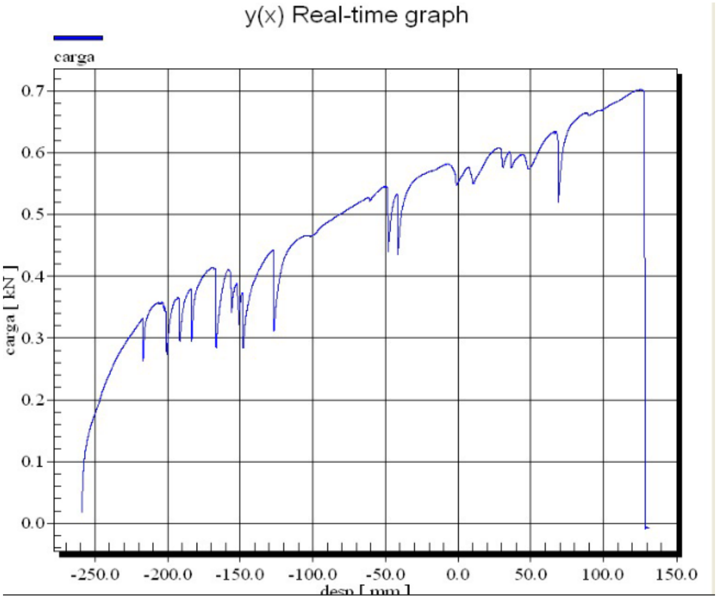
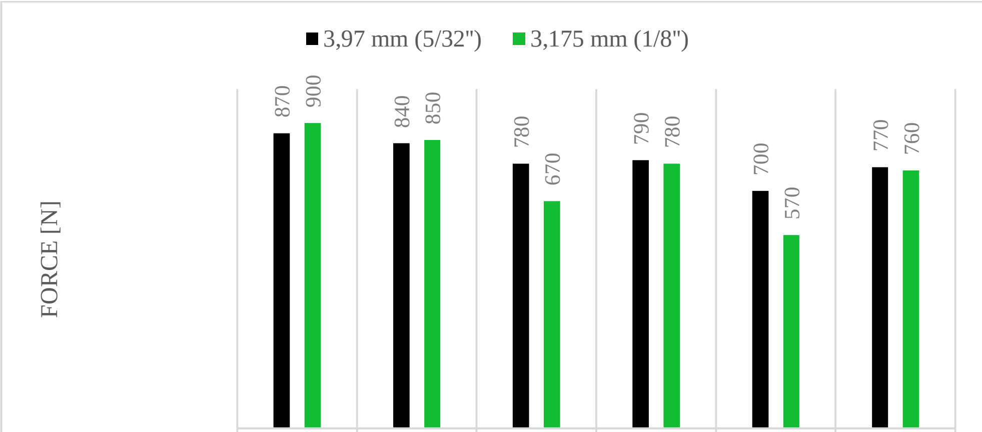


Figure 3.8: Typical recorded load-displacement curve.

After following completion of all trials, obtained data was subsequently processed. The average resistance for each knot are shown in Figure 3.9 and numerically presented in Table 3.3 for 3, 97 mm (5/32’’) diameter and Table 3.4 of the 3,175 mm (1/8’’) diameter.



	Rope	C0	C1	C2	C3	C4
3,97 mm (5/32")	870	840	780	790	700	770
3,175 mm (1/8")	900	850	670	780	570	760

Figure 3.9: Resistance obtained for different types of combined knots, in tests with two different diameters.
Numbers presented in mean values.

Table 3.3: Resistance of knots observed in tensile test with the Universal Machine. These tests were made with the 3, 97 mm (5/32'') diameter rope.

Number of test **Type of Knot**	1	2	3	Mean value [kN]	Dispersion [kN]	Loss of force compared to the rope [%]	Loss of force compared to C0 [%]
Rope	0,88	0,87	0,87	**0,87**	0,02	*	
C0	0,88	0,85	0,81	**0,84**	0,07	3,3	*
C1	0,80	0,74	0,80	**0,78**	0,07	10,8	7,8
C2	0,77	0,74	0,85	**0,79**	0,11	9,9	6,8
C3	0,69	0,70	0,70	**0,70**	0,01	20,3	17,6
C4	0,83	0,72	0,77	**0,77**	0,11	11,4	11,4

Table 3.4: Resistance knots observed in tensile test with the Universal Machine. These tests were made with the 3,175 mm (1/8'') diameter rope.

Number of test **Type of Knot**	1	2	3	Mean value [kN]	Dispersion [kN]	Loss of force compared to the rope [%]	Loss of force compared to C0 [%]
Rope	0,84	0,90	0,94	**0,90**	0,10	*	
C0	0,86	0,87	0,83	**0,85**	0,05	4,9	*
C1	0,67	0,65	0,71	**0,67**	0,06	24,63	20,8
C2	0,77	0,78	0,78	**0,78**	0,02	13,39	8,9
C3	0,59	0,56	0,56	**0,57**	0,03	36,14	32,9
C4	0,82	0,68	0,77	**0,76**	0,14	15,48	11,1

From the tables, it can be noted that knots affect the rope properties negatively. As the testing proceeded, the ropes became slimmer in transition to the knots, and all ropes finally broke at these points (Figure 3.10). It was showed that combination 3, including a total of 6 knots, broke earlier and lost more force, which are sought to be an outgrowth of more fragile points. Tensile strength is defined as force and accordingly measured in force by area (N/mm^{2}). When the cross section substantially decreases, force will increase and create fragile points.

In despite of the previous test of different rope sizes, a relationship between higher strength and larger rope diameter was defined. Moreover, combination 2 (Pulley-Gear) and combination 4 (Taut-Guard) continued to convince in behavior.

In order to improve the test, a placement of an extensometer would have been preferable. The extensometer could have recorded the changes in lengths, but might have been impossible to use due to the high violence as the ropes broke. The specimens were attached to the adapters by an Eight-Knot. It was noted that this was a good method, but did not completely secure slippage. The obtained maximum load supporting the knots were nevertheless found reliably due to a low dispersion among the specimens.

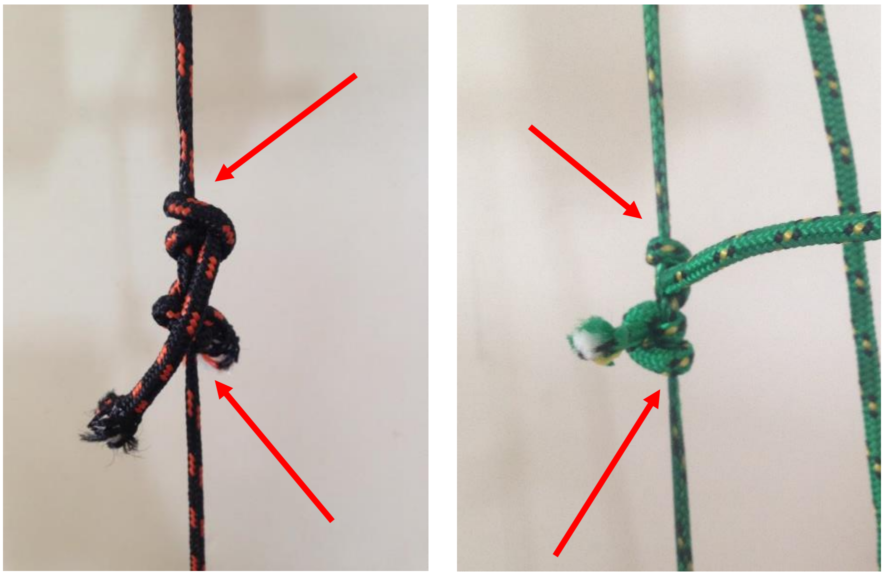


Figure 3.10: Necking of test samples (combination 4).

Table 3.5 show the sizes of the combinations tied with different rope diameters.

Table 3.5: Sizes of the combinations

Combination number	**Diameter of rope [mm]**	**Size of knot [mm]**	**Mark**
1	4,76	38	**INADEQUATE**
2	4,76	38	**INADEQUATE**
3	4,76	30	**ACCEPTABLE**
4	4,76	30	**ACCEPTABLE**
1	3,97	24	**ACCEPTABLE**
2	3,97	24	**ACCEPTABLE**
3	3,97	24	**ACCEPTABLE**
4	3,97	20	**ADEQUATE**
1	3,175	15	**ADEQUANT**
2	3,175	15	**ADEQUANT**
3	3,175	10	**ADEQUANT**
4	3,175	10	**ADEQUANT**

In contrast to the manual tensile tests, a large size of diameter is not to prefer. In fact, the 4,76 mm (3/16’’) diameter leveled and overrun the required value.

Continuously, also in contrast to prior tests, the thinnest diameter showed an approved results for all combinations.

The initial premise from practicing the knots was overruled while performing the further researches. The results of combination 2 (Pulley-Gear) confirmed that contrary to first impressions, combination 4 (Taut-Guard) might not be the most efficient option regarding tensile strength. This bring the conclusion that two combinations can be pointed out as a possible replacements for the turnbuckle. Combination 4 (Taut-Guard) access features that include an easy and fast workability whereas combination 2 (Pulley-Gear) showed high performance in tensile strength. Furthermore it was found that a thicker diameter is to prefer according maximum strength, but on the other hand it cannot be too big in order to undercut a size magnitude of 20-30 mm.

This work sought to find a replacement for the expensive turnbuckles to use as part of a reinforcement system. The investigation is found very important as an employment of a knot would decrease costs of the system tremendously. The full scale model is currently under development to get reliable analysis and design procedures. As the research will process the define premises, it is thought that also questions on the knots will be answered. The detailed step-by-step manual on how to prepare the reinforcing knot was thought to serve as help or guide to continue the research (it's difficult to explain a knot verbally), and while updating an adobe construction manual (Blondet, Vargas, Sosa, & Soto, 2014) with the implementation of the knots.

3.2 Preparing test work of the portable shaking table

This segment of the report shows the compiled results of the development of the portable shaking table and small scale adobe models. The preparing test work aimed to efficient the portable shaking table for on-site demonstrations, in terms of simulation of the latest reinforcement method with nylon ropes, time efficiency and creation of seismic awareness.

3.2.1 Modeling: Non-reinforced and reinforced small scale adobe houses

The modeling aim to create time efficient small scale adobe houses, traditional and revisions improved with reinforcement. One traditional and two unreinforced were built and evaluated.

There were some changes between the two reinforced models. It was found that a lean-to roof did not allow the collar beam to connect to the walls and bricks at the upper part of the walls separated early. The crossties were also excluded in Model 3. The crossties were difficult to tie and time consuming. The main purpose of crossties are to reduce differential displacements to provide a through-wall connection (Blondet, Villa Garcia, Brzev, & Rubiños, 2011). However, Marcial Blondet et.al (2014) discovered that the crossties are not at great impact, except at the upper parts of the walls. Accordingly, the disclosure did not affect the performance of the models.

The exclusion of mortar of models, eliminated waiting time for drying. According to Marcial Blondet and Alvaro Rubiño (2014) a completing time for a house model was 7 days. Of the present models, the bricklaying was done within a day of the non-reinforced and two days of the reinforced. One disadvantage was the disparity in simulating a traditional building technique. As the contemporary project seeks to impress upon consequences of living seismically unsafe houses, without educational contents, the models were thought satisfactory. Nevertheless, it is suggested for continuous work to investigate the outcome of mortar. Figure 3.11 shows the difference between a model including mortar, and contemporary models. Moreover, it is easier to identify the reinforced model in the present model, due to the superficial yarn.

Figure 3.11: To the left shows previous reinforced test model, including mortar. To the right, the new reinforced model.

In a series of cases the exceeded table was found very efficient as it allowed a direct comparison in behaviors of an unreinforced and reinforced model. Moreover, the new table allowed a parallel preparation of the models directly on site, which prevented risks for damage in transportation and carriage Figure 3.12.

Figure 3.12: To the left, the previous shaking table allowing testing of one single model. TO the right, showing the extended table allowing parallel demonstration.

3.2.2 Subjecting the adobe house replicas to earthquake-like forces

The models were exhibited in two sequences. First, a single reinforced house. Secondly, a traditional and a reinforced model parallel. The exhibitions were recorded and one is available at https://www.youtube.com/watch?v=rbbcBLlWoDA. Following figures show scenes from the video.

The reinforced model had great dynamic response, even though it suffered some damages. Analysis of obtained data show that the models reacts similar to a real house structure put under seismic forces. Accordingly, this proves that the model were successfully reality anchored. Figure 3.13-3.15 show a similarities in cracking scheme as earthquake damaged houses in Pullo and the full scale model. The figures also demonstrate features of the reinforcement trying to hold the house together.

Figure 3.13: Partial collapse of walls and roof

Figure 3.14: Vertical cracking in walls

Figure 3.15*:* Diagonal cracking at opening (Blondet, Vargas, Sosa, & Soto, 2014) (Cribilleros, et al., 2014).

The testing results showed that the yarn provided the reinforced house model from collapse whereas the unreinforced house model collapsed immediately (Figure *3.16*3.16). To improve the transference of awareness, and to evaluate the outcome of an in-site demonstration, questionnaires and open discussion with the audience are suggested. It is thought to be important in order to measure emotional and psychological impact.

Figure 3.16: Left picture show the models about to be tested. The right picture show the collapse of the non-reinforced model.

3.3 Situational evaluation and raising the seismic awareness

It is not an easy trip to reach Pullo. The road between Acarí and Pullo is part of a non-maintained dirt track passing through the desert, winding up the mountains to a height of 4000 meter ASL, and down again through the valleys until Pullo is reached after about 7 hours. The road offers an amazing nature experience, small single dwellings and agriculture. Even before reaching Pullo, the poorness and primitiveness of this area shows (Figure *3.17*3.17).

Figure 3.17: View on the way to Pullo

The reality in Pullo is by all means difficult. Many houses lack basic building technic criteria and are very dilapidated by the pass of time. The main material used is adobe because it's the only economically available for most families. Despite everything said, Pullo is experienced as a beautiful, calm and quite village inhabited by traditional highland people (Figure ***3.18***3.18a). Every Sunday the people gather at the main square to raise the flag for the district in order to establish a sense of solidarity (Figure ***3.18***3.18b-c). Since three years the Catholic Church has tried to convert people, and even though no priest is present, 6 nuns dwell in the church. In line with that, Caritas Caravelí´s interest on Pullo can be explained. Figure 3.19 shows two of the engineers together with nuns and a representative from the Caritas.

(b)

(a) (c)

Figure 3.18: a) Two traditionally dressed children, b) the main square of Pullo, c) The raising of the flag ceremony.

Figure 3.19: Two of the nuns and the representative of the Caritas Caravelí together with the engineers.

In interviews, it was found that the people are very scared of a repeated situation such as the one in 2014. They are aware of the perils of a natural disaster such as earthquakes, but they are not aware of the vulnerability of adobe houses and their living situation.

Lic Graciela (Figure 3.20), living in an adobe house on the main square, explains how scared she was during the earthquake. She left her house and ran out to the square. There she gathered with other residents that also had fled their homes. Together they tried to figure measures to take. She describes how they wanted to enter the church where the nuns were praying and chanting, but the church was shaking and damaged so they hesitated. She said that she doesn’t know what to do or where to go as an earthquake occur.

Hernan Negra (Figure 3.20), an old man inhabiting an adobe dwelling built in 1901, remember the earthquake from 2001. He explains how the streets opened up, how the houses raged. “Earthquakes are dangerous, ugly and terrible”, he says. Likewise Lic, he doesn’t know where to go to get protection.

Figure 3.20: Lic Graciela to the left in interview with Malena, and Hernan Negra to the right.

For the team of PUCP to establish a reliable cooperation with the community, a meeting with the authorities of the district (major, manager of the municipality, city hall consul) was held. In discussion it was concluded that the project in a first phase must focus on reconstruction of a building, however the authorities pointed out a need of new houses as well.

To present the work done and the diagnosis set by the team, a workshop was held with the residents. This part included a demonstration with the shaking table. 52 people joined the event and over 30 people signed up to participate on the training project (Figure *3.21*3.21). This was found very successful. Furthermore, it indicated progressing of the project. Cribelleros (2014) stated that about 20 people joined the workshop on last field visit.

Figure 3.21: Work-shop with the inhabitants. People signing up for the

training program.

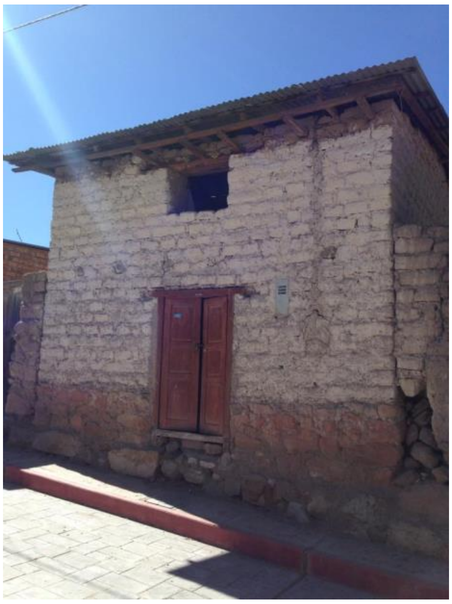
Following sections will describe the currently building situation and available reinforcement materials. Moreover, it seeks to show the outline of the approach of an in-situ demonstration with the portable shaking table.

3.3.2 Evaluation of the current building situation

Whereas creating awareness and willingness to accept help was a first step towards the long term goals of the project, know-how transference of adequate building criteria were planned next. In order to prepare for the following phase, a site evaluation was performed to collect information on existing buildings´ characteristics so that a reinforcement program could be continuously improved. A seismic risk analysis has not yet been done, but the material gathered is thought to be proceeded in future phases of the project.

From a visual perspective there are two house types in Pullo. When studying the houses closer, it is found that the two typical houses have many similarities. In fact, the difference lies in its location. People inhabiting houses on the main square, or close by, was found having greater need to maintain their houses. Therefor significant damages from the earthquake was not to be found, and a sufficient layer (ca 25 mm) of colored mud plaster gypsum covered the facades. Figure 3.22a-b shows the area close to the main square and Figure 3.22c-d quarters further out from the center.


(a) (b)




(d) (e)

Figure 3.22: Typical adobe houses in Pullo; (a) and (b) houses close by the center of the village whereas (c) and (d) show houses further away

In general, the construction of the houses is performed with two types of brick lying; the traditional (a technique used in the small scale models) and an American style (*Amare Americano*) (Figure 3.23). The traditional technique is performed with square bricks, with dimensions of for example 40x40x10 mm^3, whereas the American style are built with rectangular bricks, dimensioning for example 40x20x10 mm^3. The American style is thought to be more vulnerable to seismic forces, as the walls gets thicker leading to a greater massiveness and brittleness.

Figure 3.23: To the left the American style, and to the right a traditional brick laying.

The houses in Pullo are built two stories high with a rectangular or square planning (Figure 3.24a). A main door is placed centered in one of the longer walls, and a small windows (also centered) are common at upper part of one or two walls (to light the second floor). Foundations plinths consist of a drywall made of mud and stones (Figure 3.24b). Normally a slightly inclined pitched roof is built (Figure 3.24c) with a coverage containing either thatched or corrugated steel (Figure 3.24d). Ceilings are made of wood logs resting directly on the walls (Figure 3.24c-d). Rainwater is drained along the roof edges (Figure 3.24e). Wall joints are between 40-80 mm, filled with mortar both vertically and horizontally (Figure 3.24f).

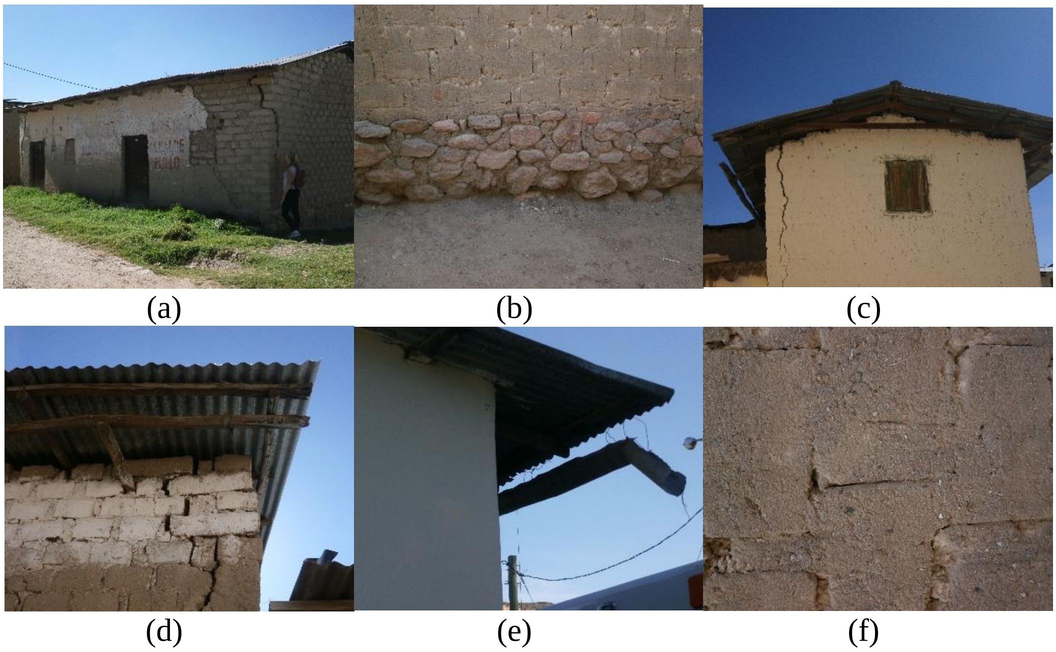


Figure 3.24: (a) Two stories house with a pitched roof, (b) drywall foundation, (c) ceiling of wood resting directly on house walls, (d) Typical roof material, (e) water draining, (f) brick joints filled with mortar.

The earthquake, occurring in August 2014, caused structural damages on many adobe houses, mainly on those due to obsolescence could not resist the seismic forces. In the second visit many deficiencies were still to be find. Many of these damages similar those summed by Blondet et al. (2011). Figure 3.25 show partial collapse of adobe walls. The pitched roof makes the upper part of the walls fragile. Generally, it is the tallest wall that are damaged first.

Figure 3.25: Partial wall collapse

Due to the lightweight roof constructions, seismic forces makes the walls vibrate which in turn make them perpendicular to each other. This creates large stresses at the upper corners of the walls generating vertical cracks as shown in Figure 3.26.

Figure 3.26: Vertical cracking

Diagonally extending cracks presented at upper or lower corners of opening is caused by shear forces. They are due to stress concentration at the corners of the openings and the incompatibility of adobe and material of the lintels (Figure 3.27).

Figure 3.27: Diagonal crack near openings

Figure 3.28a show a typical cracks of free standing walls from the team´s first trip to Pullo. The cracking occur near the basement of the houses. Size of the damage depend on the wall thickness (King, 1996). The wall encircles the public arena for bull-fighting, and was heavily damaged (Figure 3.28b). During the stay, local foremen reconstructed one of the most destructed part of the wall. This is a clear indication on how people priorities reconstruction of commercial buildings, instead of their own homes, which are in greater need (Figure 3.29a). The adobe bricks used in the reconstruction, shown in Figure 3.29b, were bought from a local foremen, and cost about 0,3 US$ (1 sol) per brick. The foremen recycled damaged adobe bricks to make mud mortar.

(a) (b)

Figure 3.28: (a) the bull-fight arena and (b) the damages of a freestanding adobe wall (Photo: M Serrano)

(a) (b)

Figure 3.29: (a) reconstruction of a wall damaged in the earthquake and (b) the adobe bricks used to do so.

The drying site of the sold adobe bricks was found, as shown in Figure 3.30. The ground was dry and clean, but the site had no protection for wind nor rain which can lead to great decreases in sustainability of the bricks.

Figure 3.30: Drying site for adobe bricks

The damages of adobe bricks around the village indicate that the soil selection is poor and causes low-resistant bricks. To investigate the soil properties, a sample of prepared mud plaster (Figure 3.31a) was tested by the dry strength test. It was found that the soil had adequate features (Figure 3.31b), a result that was unexpected. The test was taken from a garden belonging to Gamaniel Chilcilches Orio, the judge of piece of Pullo, as he at the time was building an improved kitchen. The preparing of mud plaster and the improved kitchen can be found in Figure 3.32. Gamaniel was well familiar with the importance of making a drying strength test. An additional test sample of soil was brought to PUCP´s lab for further analysis.

(a) (b)

Figure 3.31: (a) Making mud balls, 20 mm in diameter, (b) trying to crush the ball between thumb and index finger.

Figure 3.32: The improved kitchen and preparation of mud plaster in the garden.

It was thought that the people had no criteria to select suitable land to fabric adobe blocks. In despite, Gamaniel explained that for his soil he paid the municipal 7 US$ (20 soles). The soil was then collected from a commercial football field (Figure 3.33). He also describes how he paid about 10 US$ (20-30) soles for a pick-up truck to dig and transport the soil to his home.

Figure 3.33: The football field where people can buy soil to make adobe bricks

Even though soil properties, as far as drying strength and site conditions, were found adequate, the traditional building technique can be confirmed vulnerable to earthquakes. In general, buildings are constructed without technical or designing assistance. Heavy, weak and fragile walls are not able to resist seismic forces leading to cracking, separation of walls and in some cases collapse. Unnecessary thickness of mortar (joining the bricks) decrease wall stability. Thick wall joints reduce the strength of the walls. The roofs contains no collar beam to allow joining of the walls and support of the roof logs during an earthquake. Finally, adjacent buildings are not tied together which can lead to collision of the walls (Figure 3.34). Despite absence of many appropriate earthquake resistant features, the main urgency lies in age and lack of maintenance. Majority of houses sees between 50 and 100 years (Figure 3.35).

Figure 3.34: Buildings are not tied together

Figure 3.35: Aged house deficiencies

An additional perspective of the investigation was to find how available the proposed reinforcement material (halyard ropes) are. In two small miscellaneous shops, similar ropes to those of the proposed reinforcement system were found (Figure 3.36). In conclusion, the nylon ropes are viable, which by all means is an important finding. Diameters of the ropes were mainly of greater size than the ones presented in the lab-tests at PUCP. However one rope with diameter of 6,35 mm (¼’’) were found, which is the one used in the full scale model tested in 2013 (Blondet, Vargas, Sosa, & Soto, 2014). The shops did not access more than one cone of rope, and was sold for about 0,3 USD (1 sol) per meter.

Figure 3.36: The ropes were found in a small miscellaneous shop.

In evaluation which building that should be subjected for the reconstructing program, further research has to be done. None of the public buildings investigated (school, church, and hospital) was found significantly damaged or having a suitable structure for the project. In the workshop, two suggestions were given by the residents. The first included making plots of unused land, which people can buy and build new reinforced houses. Secondly, the community has collective farming house, which is in need of improvement.

To continue the project, focus has to be put on developing the reinforcement system. The full scale test performed at PUCP has only been done on one-floor models. As all buildings in Pullo have two stories, and there is no research done on such structure, this must be taken under concern. Furthermore, it is suggested that a manual for reconstruction should be introduced. The manual developed by Marcial Blondet and Alvaro Rubiño (2010) only serve for new constructions.

3.3.1 In-situ demonstration of the portable shaking table

When evaluating the transportation of the shaking table and its pertinence, it was found important to consider the means of transport. The easiest, and suggested, way is to carry the devices is by a pick-up truck. However it is suggested to modify the device in order to make it lighter and more portable. The adobe pieces have to be carefully packed, in order to avoid damage in transportation.

The portable shaking table created a fun and informal education environment. It is believed that collaboration and interaction was a successfully way to motivate and establish relationships between the inhabitants of Pullo and the research team. In the end of the performance people were asked to raise their hand if believing in improved adobe houses. A majority of the audience raised hand (Figure 3.37). Moreover, bringing elements of the research into field, made the people understand that PUCP are working forward together with them to find better housing solutions.

Figure 3.37: Demonstration with the portable shaking table. People raising hand to join the training program.

The performance with the shaking table exemplified earthquake performance with traditional and improved structural prerequisite. In experience it was found that the proposed design was accepted by people because the models were modifications of their traditional ones. The demonstration increased the confidence of people that simple techniques can make houses a tremendous amount safer. It is thought that the passive attitude of the inhabitants, defined by Cribelleros et al. (2014), is overcome by this second visit. Ordinary people, local workmen and authorities were found enhanced of the importance of including earthquake resistant characters on their traditional housing construction.

It is suggested that the shaking table should be demonstrated once more to remind the inhabitant of the vulnerability in their contemporary situation. As the presented phase of the project seeks to create awareness and willingness of participation, it is suggested for future studies to develop the device in order of technological transfer. According to Cribillios et al. (2014) population of Pullo has an illiteracy rate of 13, 7 %. In accordance, building small scale models are thought to ease the theoretical transfer of the training program.

4 Conclusions

The work described in this thesis is all parts of a long term project to improve seismic-resistant design of adobe houses in vulnerable areas of Peru, and indirectly increase quality of lives. It is substantial that all aspects of the project must cooperate to achieve the goals. The situation in Pullo is complex and vulnerable. However the project is proceeding as people now are aware of the vulnerability of their current situation. The project is at this point aiming for a reconstruction, but a target building is not yet subjected. However, the building techniques and soil properties have been evaluated.

While presenting the portable shaking table, the interdisciplinary research group was able to persuade the inhabitants in a small Andean community of the importance of their participation on a training program. Today, over 30 people have signed up and are waiting for the next phase of the program to set its start.

The use of nylon rope mesh on the small scale models, was a first implementation of the subjected reinforcement system. The material, called halyards, is found commercially available in Pullo. Further researches are necessary to determine various features of the reinforcement system of these nylon ropes. In conclusion of various tensile tests with the ropes, two combinations of knots were having beneficial properties that could serve as a replacement of the expensive turnbuckle. Nevertheless, results were found invalid in a comparison of turnbuckle used in the full scale model tested in 2013. Moreover, in general all houses in Pullo comprises two stories, but no tests have ever been performed on such models.

In summary; a seismic awareness and cooperation willingness is established in Pullo and people are waiting for the opportunity to improve their houses. On the other hand, the purposed way of doing so, which comprises reinforcing with nylon ropes, are not yet completely developed.

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APPENDIX A

Following data was obtained during maximum tensile tests with a universal test machine in the structural laboratory at PUCP.

A.1 Start values of displacements

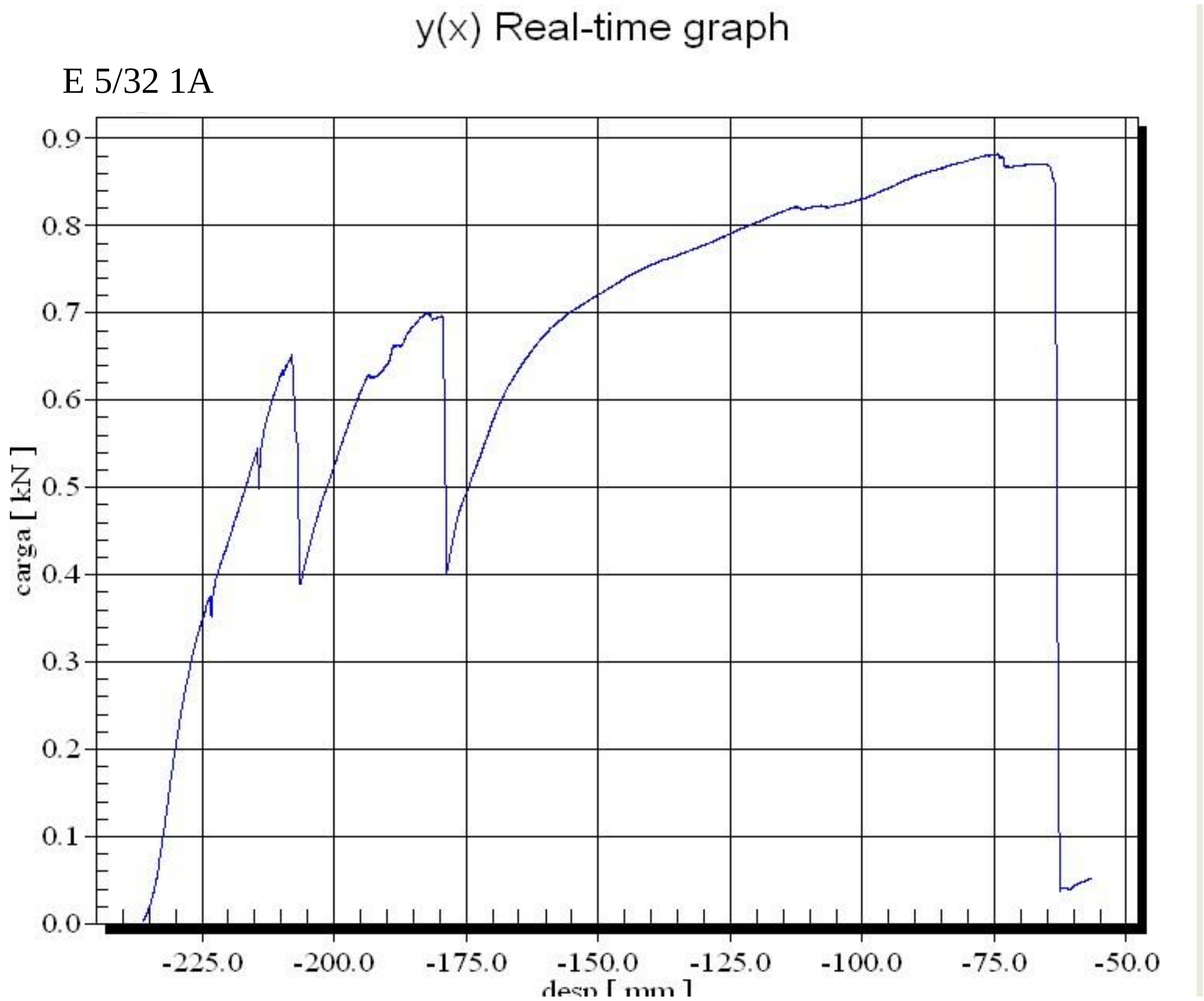
A.1.2 Test with 3,175 mm diameter

TEST TYPE	NAME OF SAMPLE	START DISTANCE OF ADAPTERS [CM]
ROPE	E181A	23
	E181B	23,5
	E181C	23,5
C0	E182A	23,5
	E182B	24
	E182C	23,5
C1	E183A	23,5
	E183B	22,5
	E183C	22,5
C2	E184A	22,5
	E184B	22,5
	E184C	23
C3	E185A	23
	E185B	23,5
	E185C	22
C4	E186A	21
	E186B	23,5
	E186C	22,5

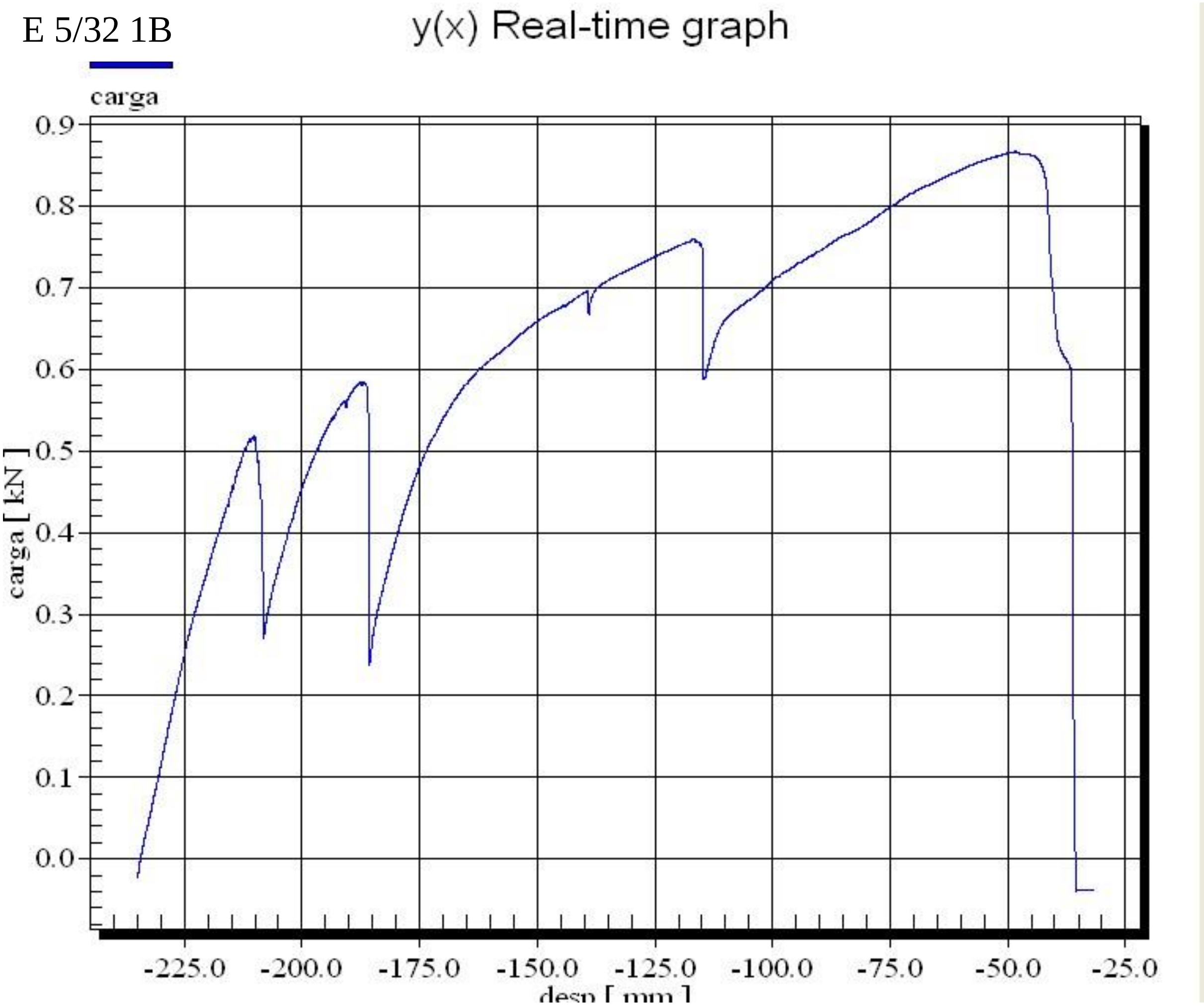
A.1.2 Test with 3, 97 mm diameter

TEST TYPE	NAME OF SAMPLE	START DISTANCE OF ADAPTERS [CM]
ROPE	E5321A	12,5
	E5321B	12
	E5321C	12
C0	E5322A	23,5
	E5322B	25
	E5322C	25
C1	E5323A	25
	E5323B	26
	E5323C	25,5
C2	E5324A	25
	E5324B	24,5
	E5324C	25,5
C3	E5325A	23,5
	E5325B	23,5
	E5325C	22
C4	E5326A	23,5
	E5326B	23
	E5326C	23,5

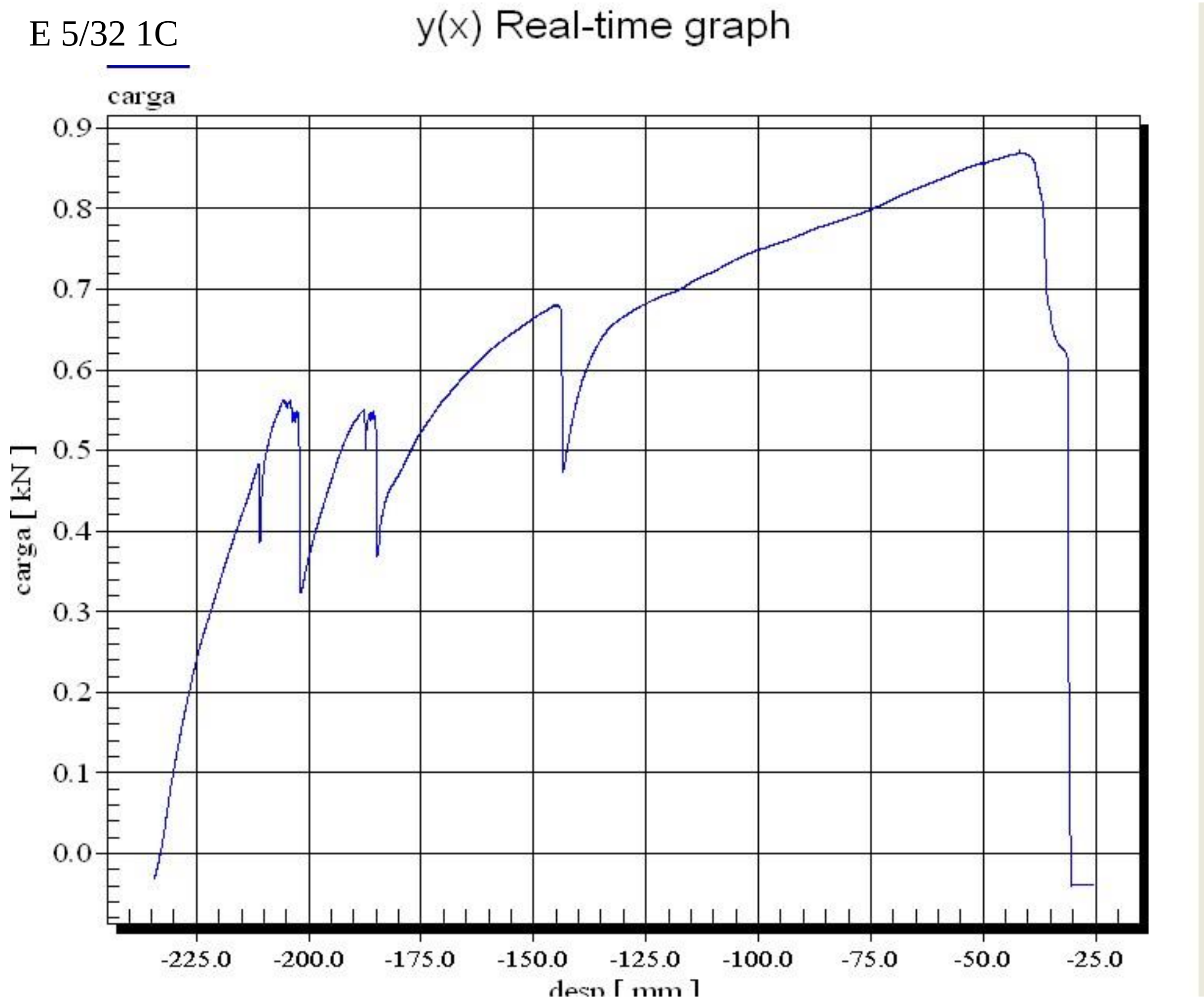
A.2 Data curves from maximum tensile tests


y(x) Real-time graph
E 5/32 1A
carga [kN]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
-225.0
-200.0
-175.0
-150.0
-125.0
-100.0
-75.0
-50.0

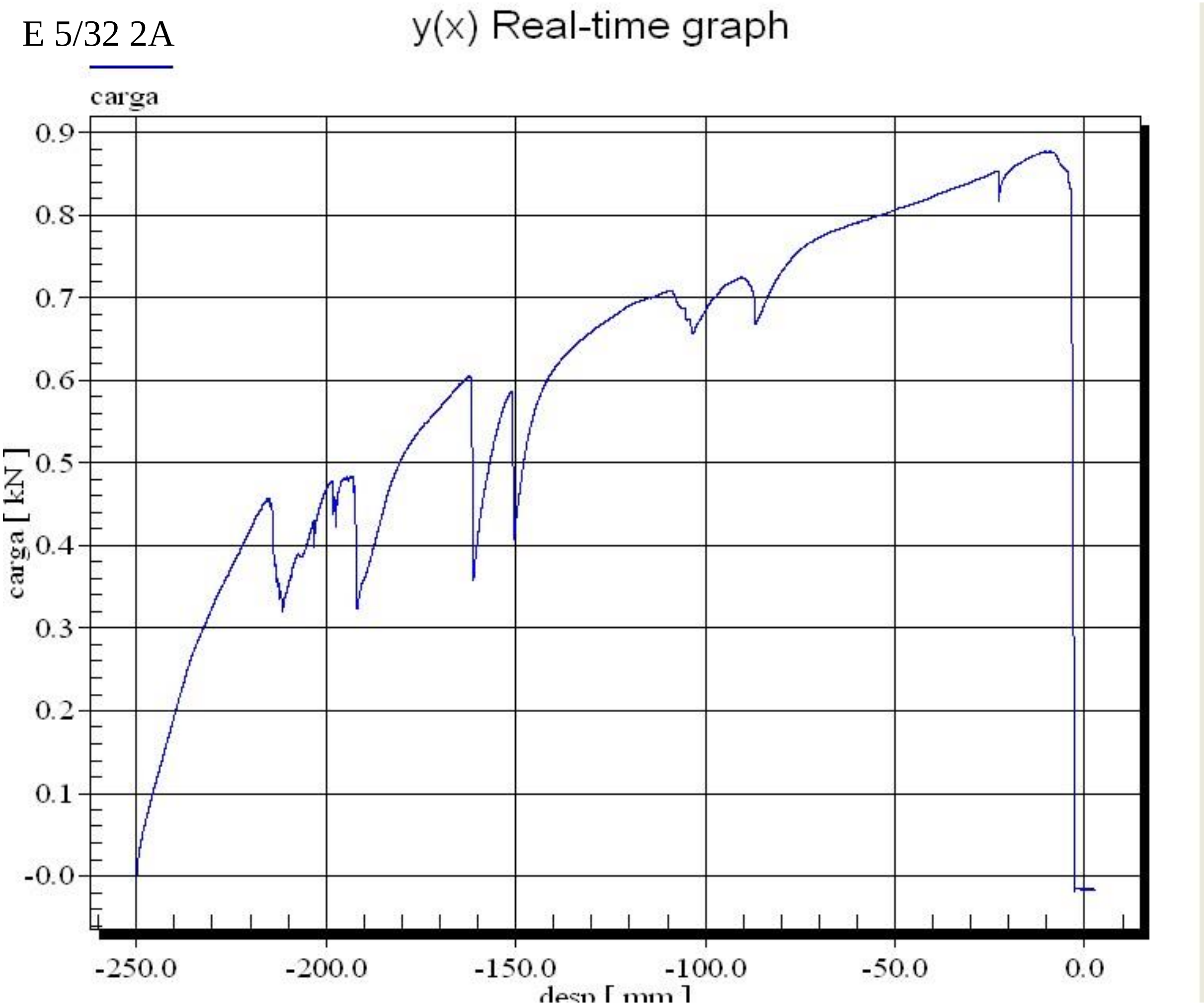
E 5/32 1B


y(x) Real-time graph
carga
carga [kN]
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-225.0
-200.0
-175.0
-150.0
-125.0
-100.0
-75.0
-50.0
-25.0
desp [mm]

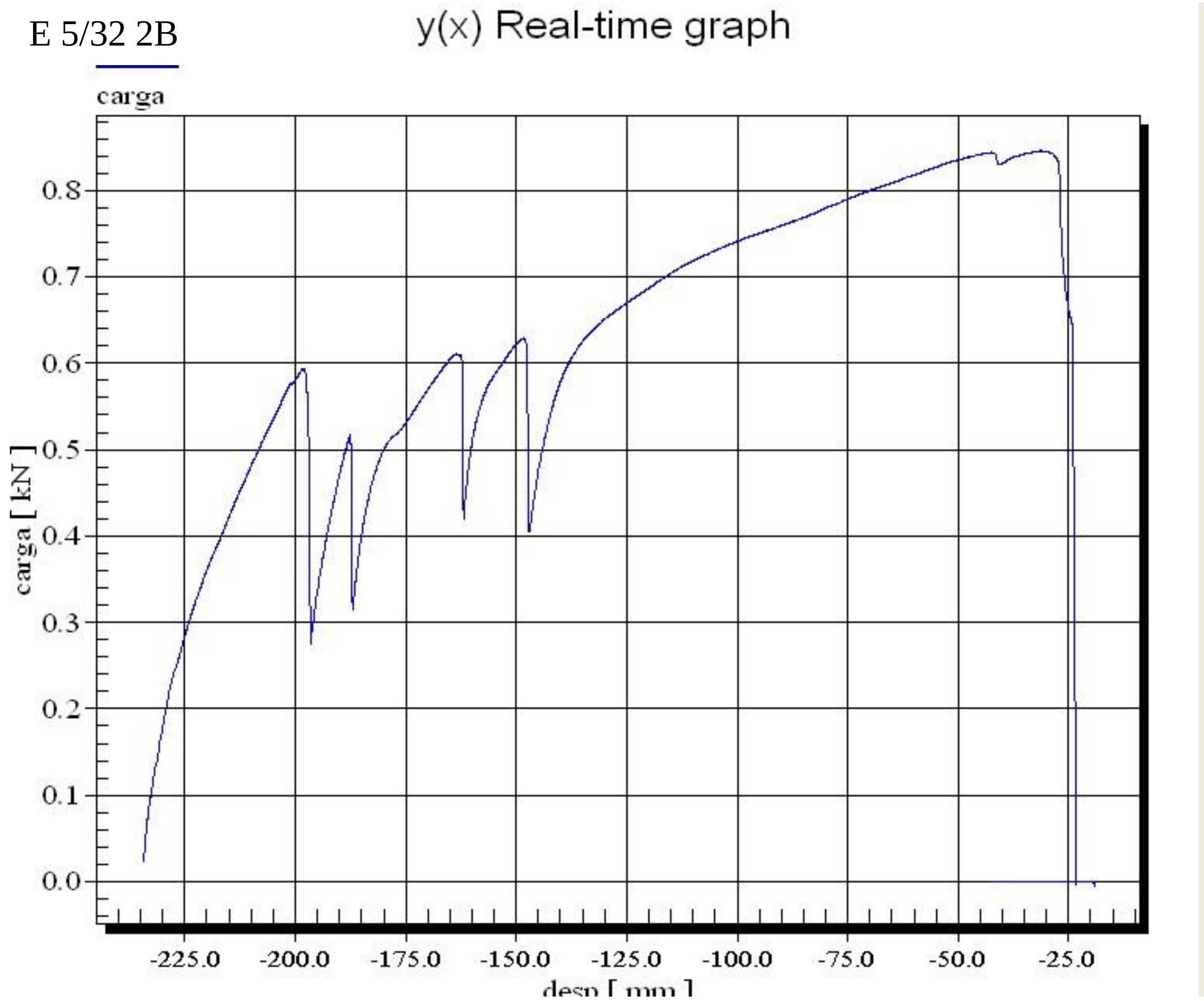
E 5/32 1C

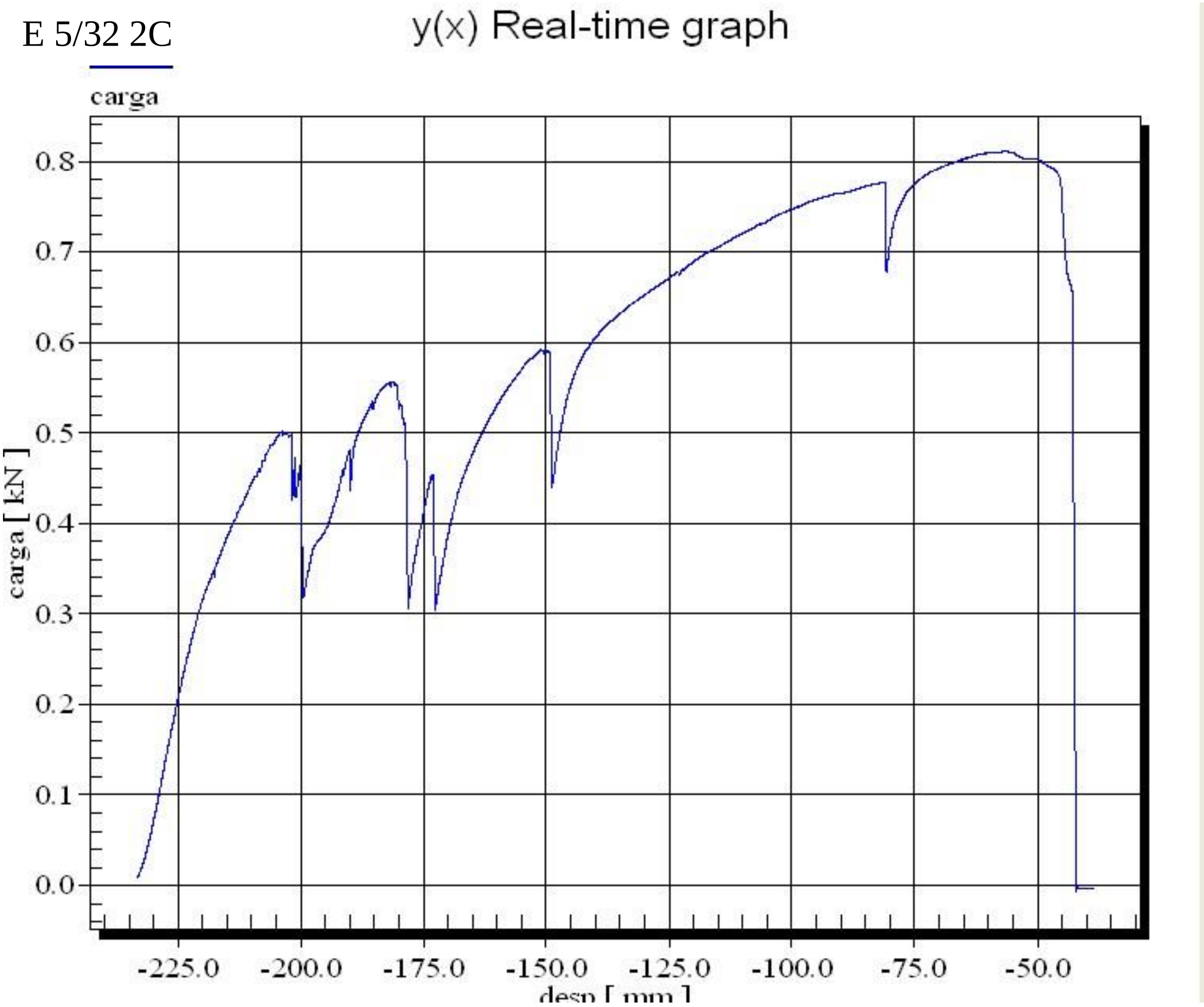

y(x) Real-time graph
carga
carga [kN]
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-225.0
-200.0
-175.0
-150.0
-125.0
-100.0
-75.0
-50.0
-25.0
desp [mm]

E 5/32 2A

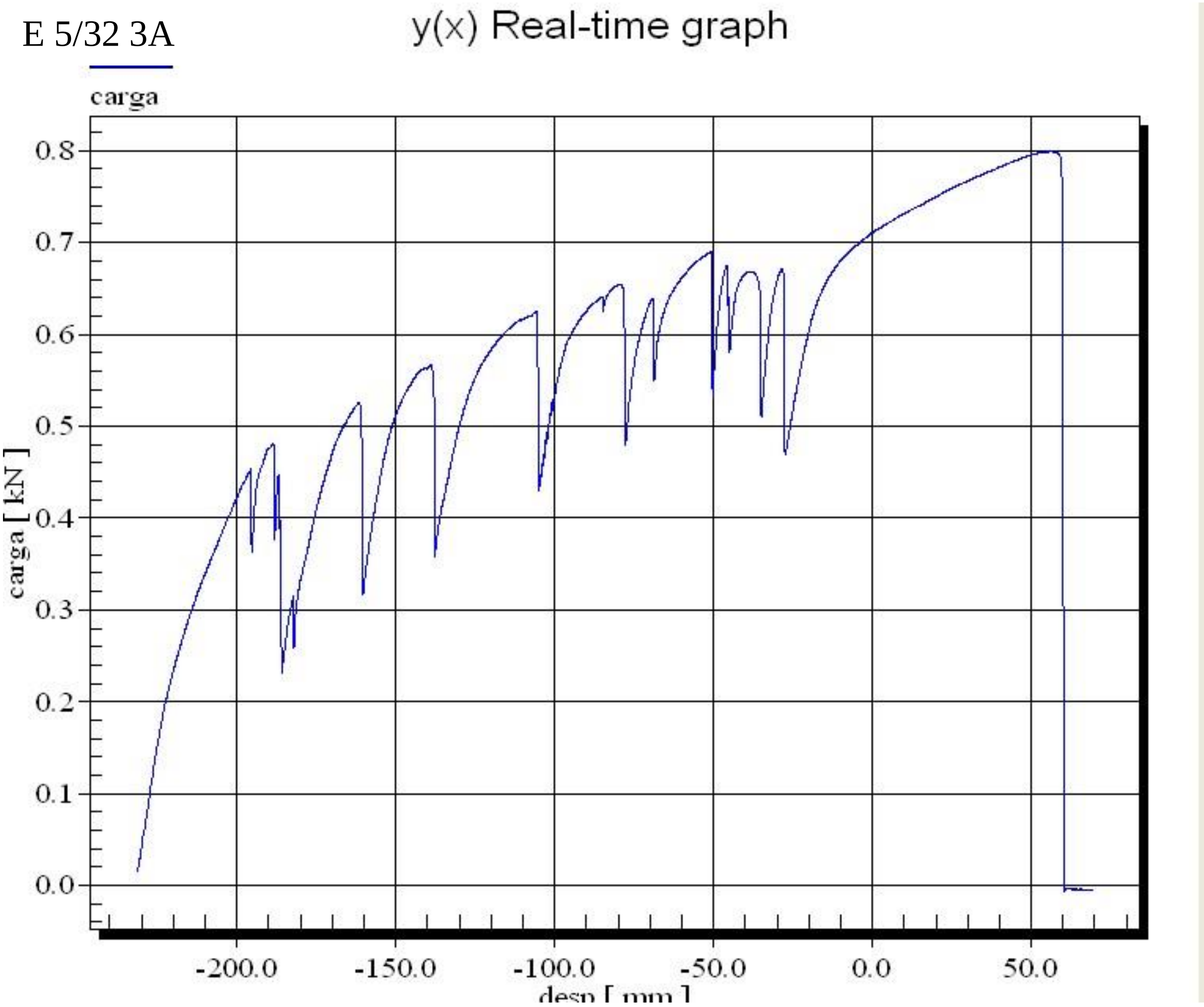

y(x) Real-time graph
carga
carga [kN]
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.0
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
desp [mm]

E 5/32 2B


y(x) Real-time graph
carga
carga [kN]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-225.0
-200.0
-175.0
-150.0
-125.0
-100.0
-75.0
-50.0
-25.0

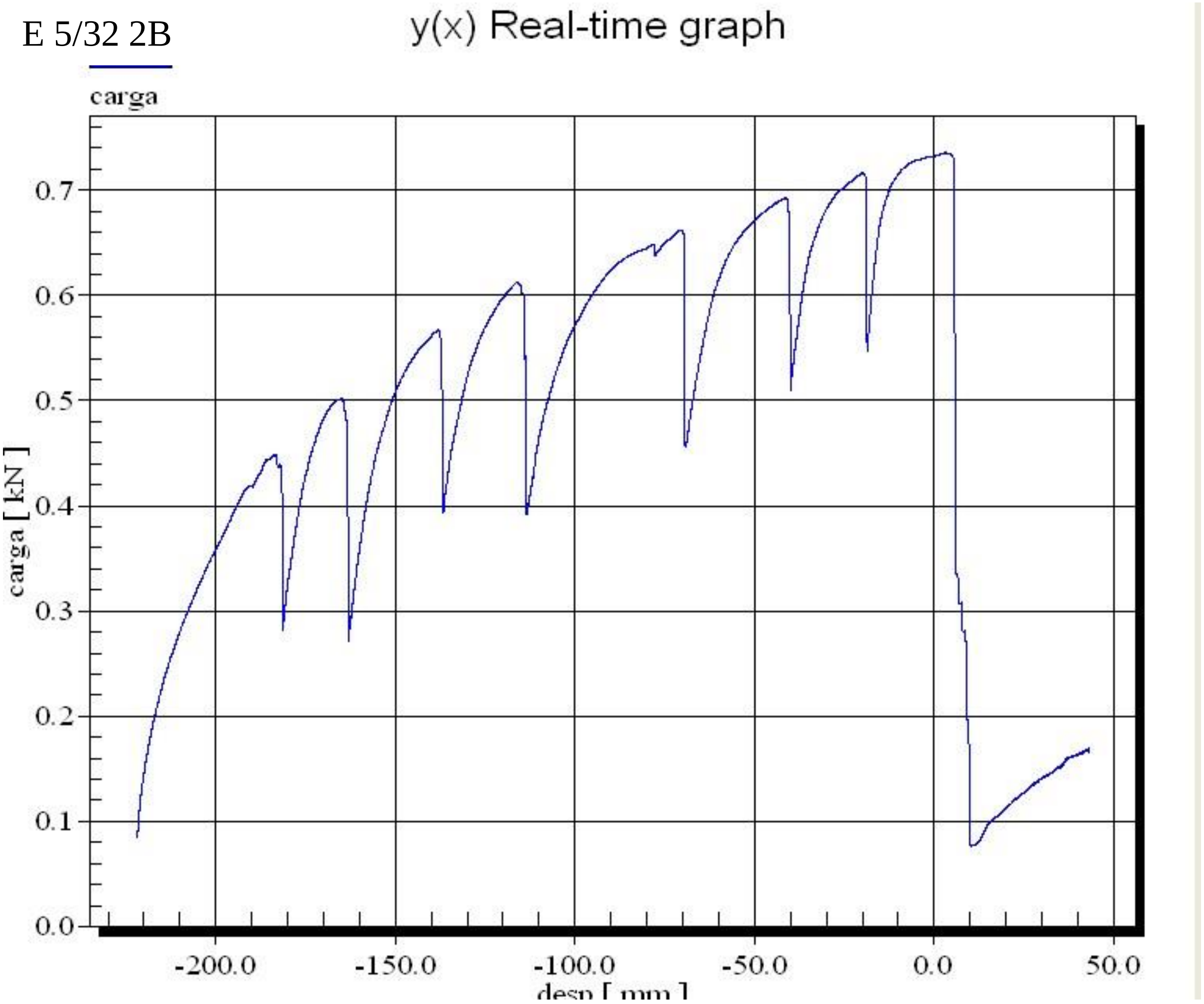

E 5/32 2C
y(x) Real-time graph
carga
carga [kN]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-225.0
-200.0
-175.0
-150.0
-125.0
-100.0
-75.0
-50.0
desp [mm]

E 5/32 3A

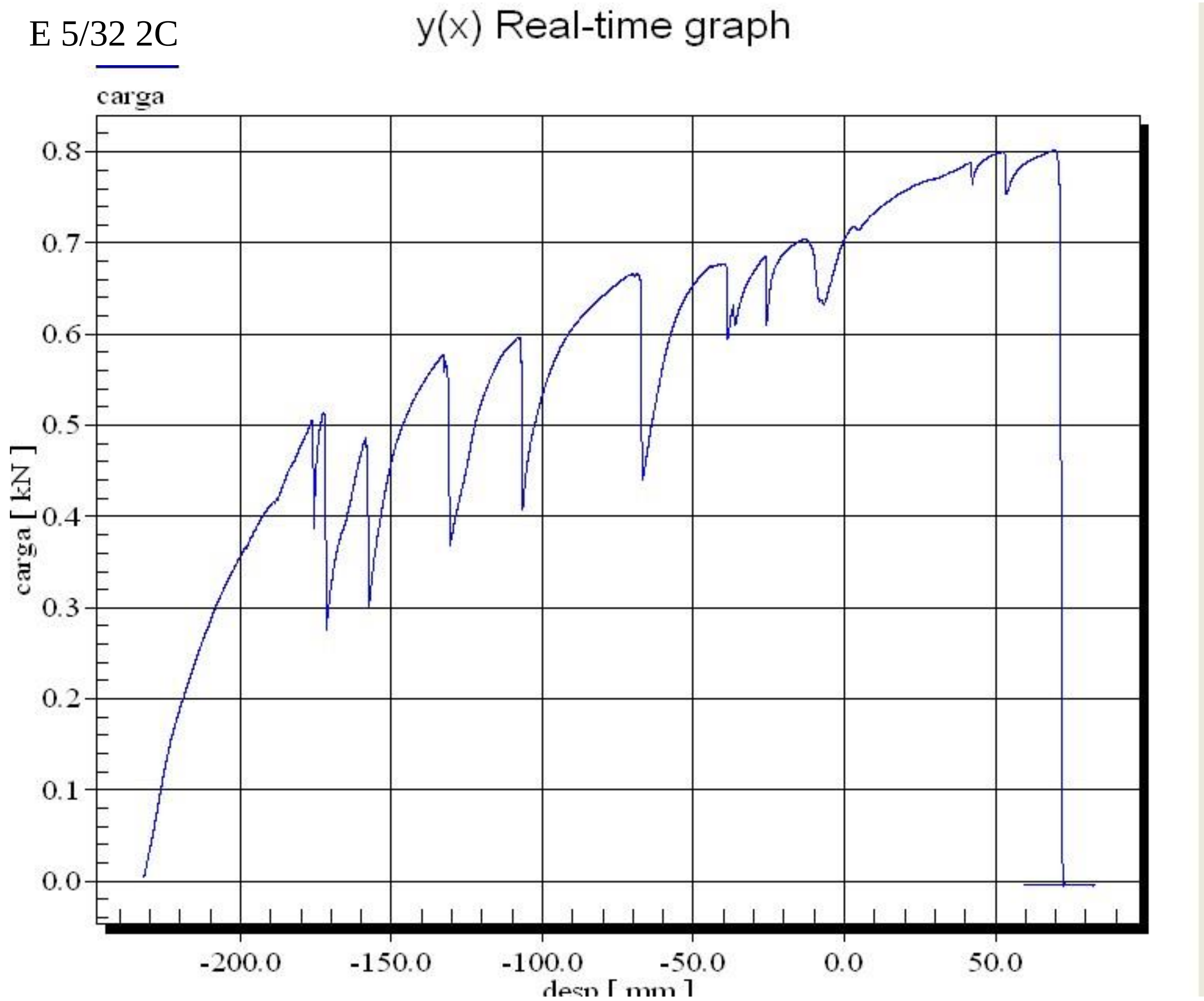


y(x) Real-time graph
carga
carga [kN]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0
desp [mm]

E 5/32 2B

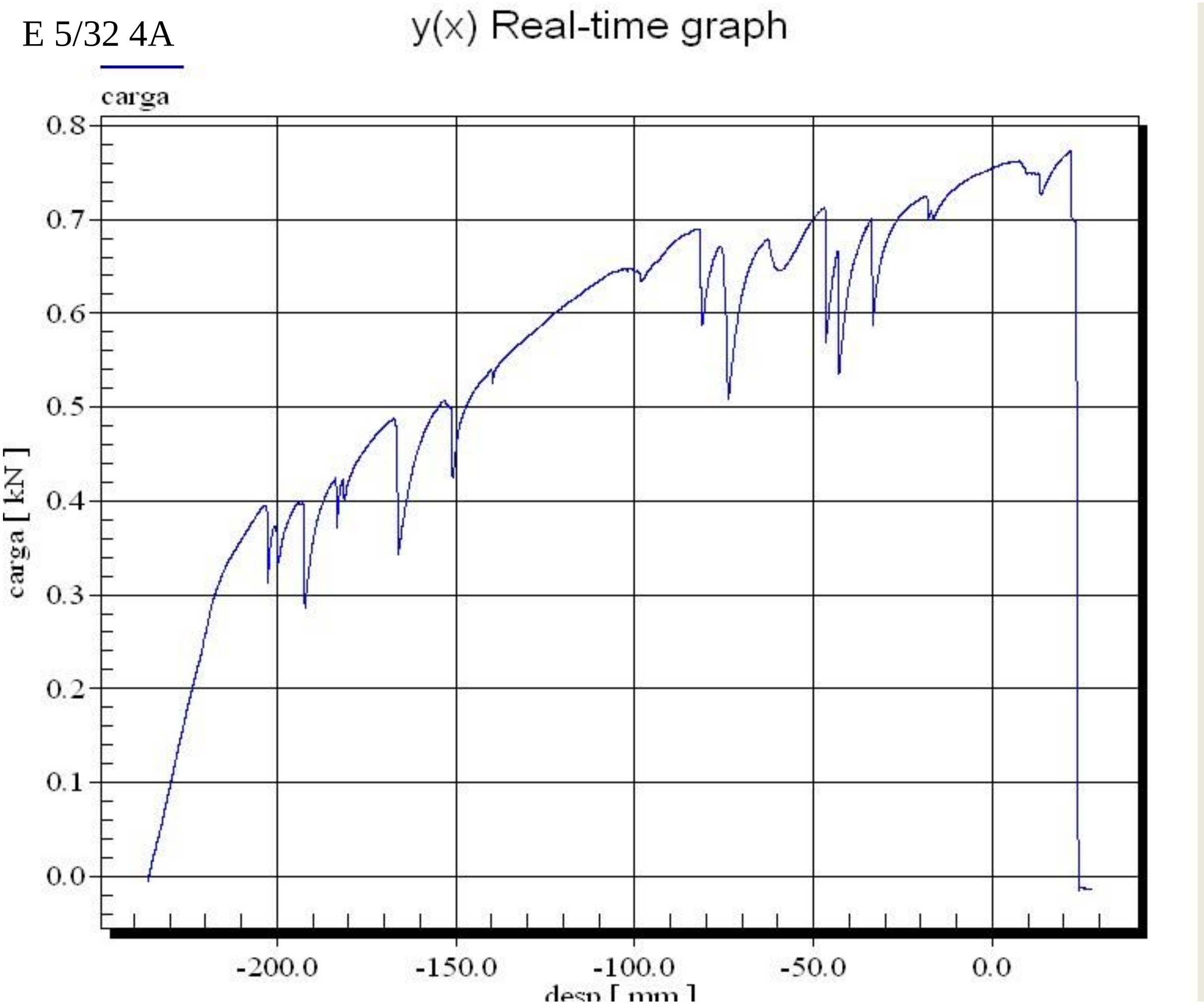

y(x) Real-time graph
carga
carga [kN]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
-200.0
-150.0
-100.0
-50.0
0.0
50.0

E 5/32 2C

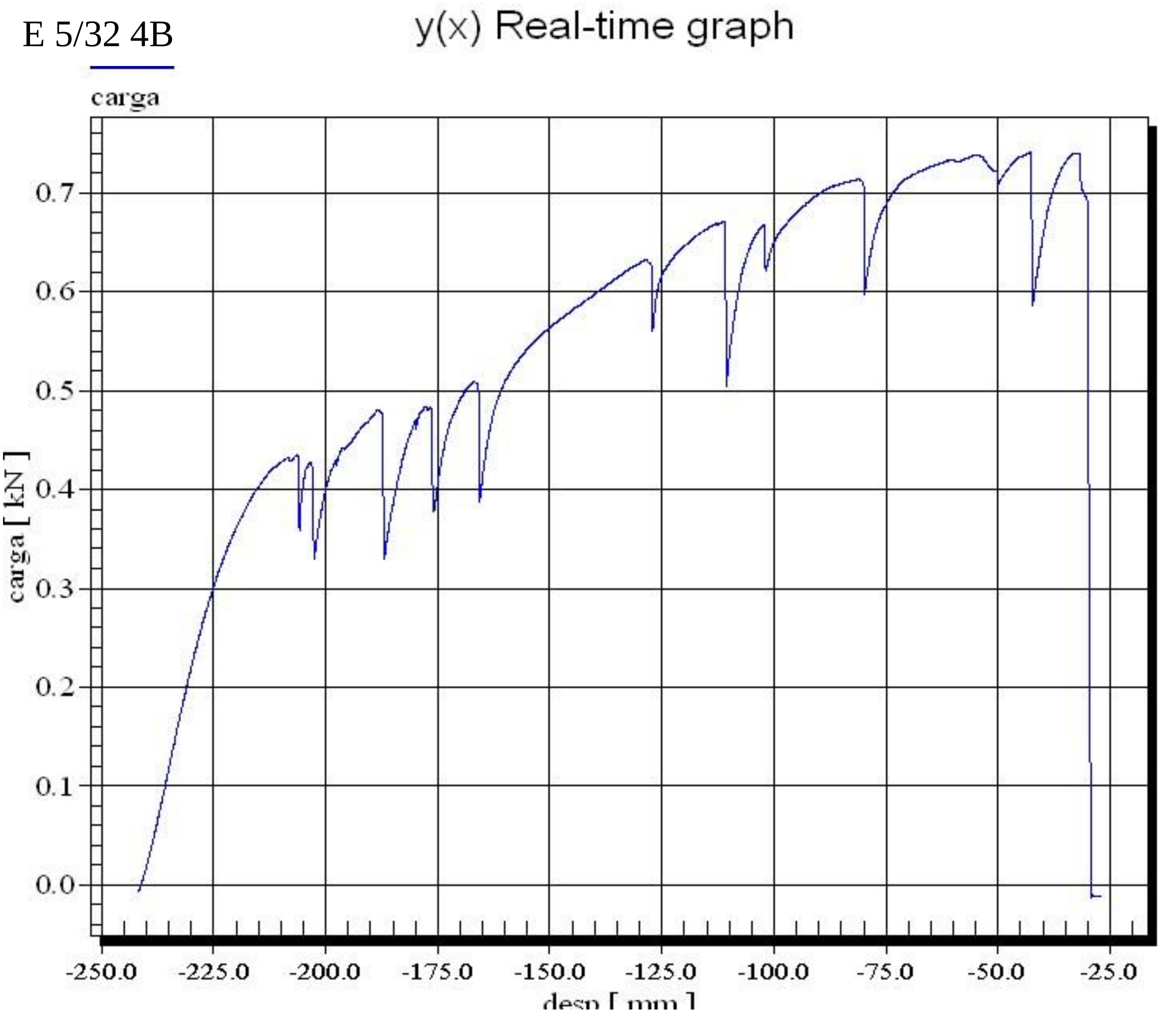


y(x) Real-time graph
carga
carga [kN]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0

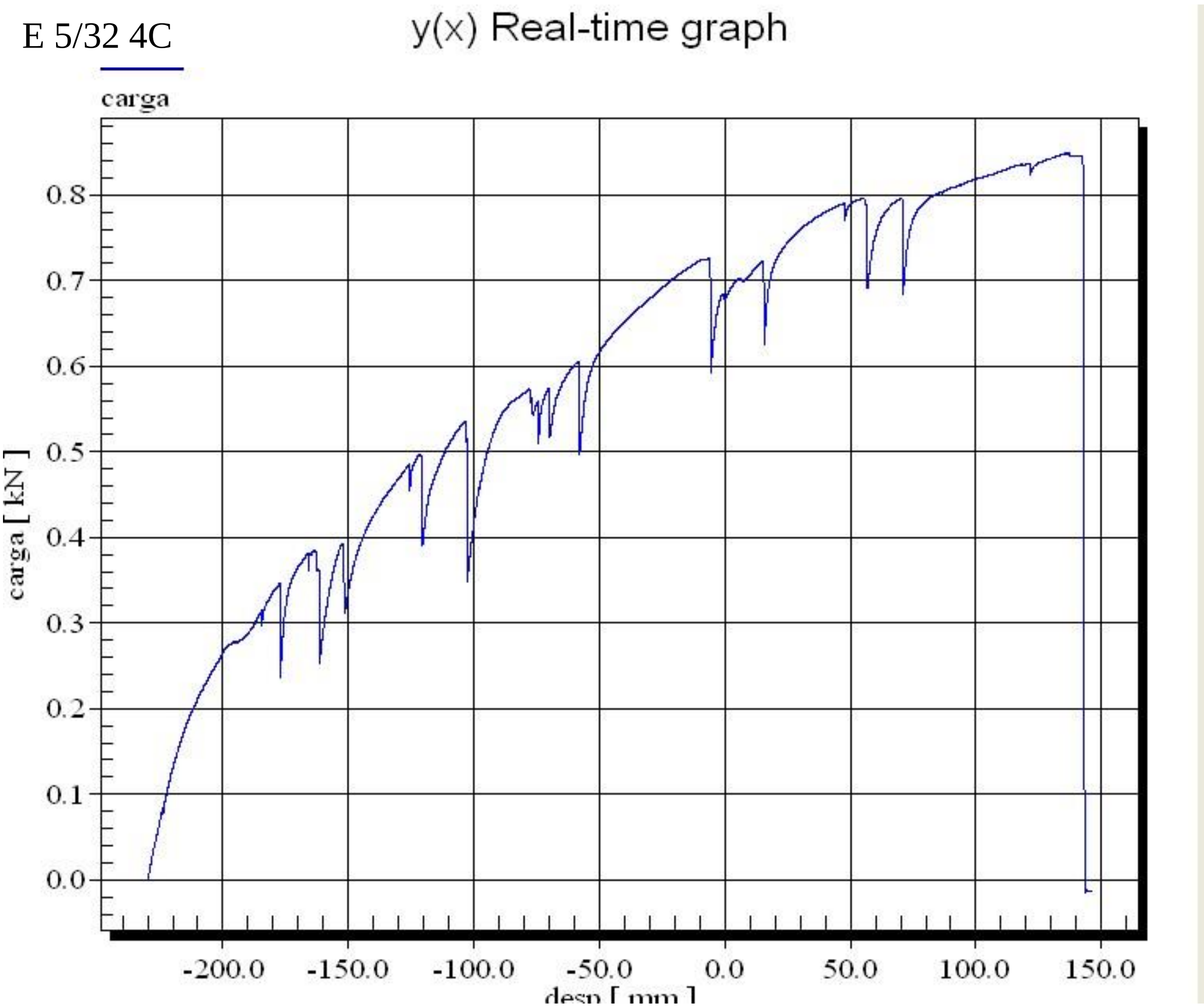
E 5/32 4A


y(x) Real-time graph
carga
carga [kN]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-200.0
-150.0
-100.0
-50.0
0.0
desp [mm]

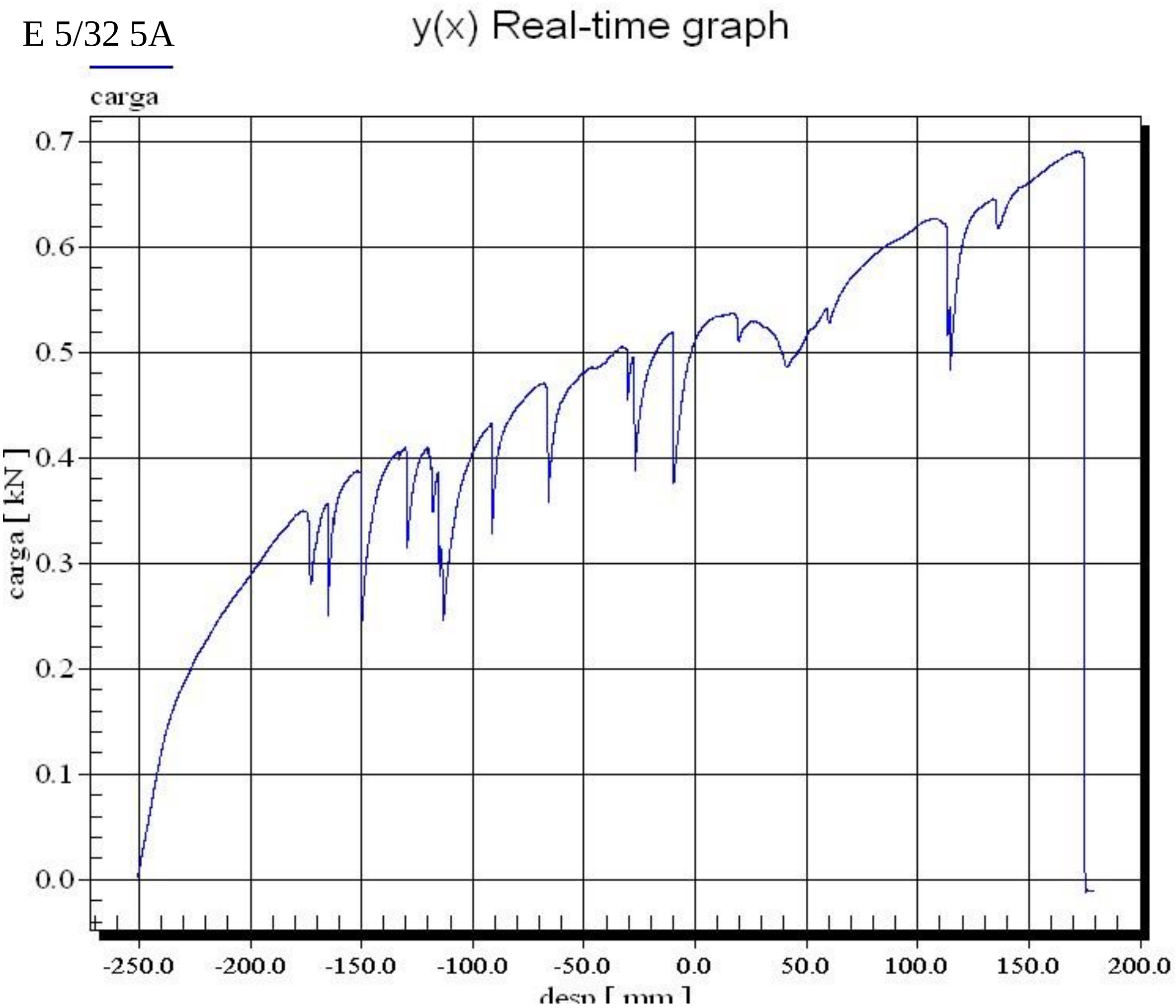
E 5/32 4B


y(x) Real-time graph
carga
carga [kN]
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-250.0
-225.0
-200.0
-175.0
-150.0
-125.0
-100.0
-75.0
-50.0
-25.0
desp [mm]

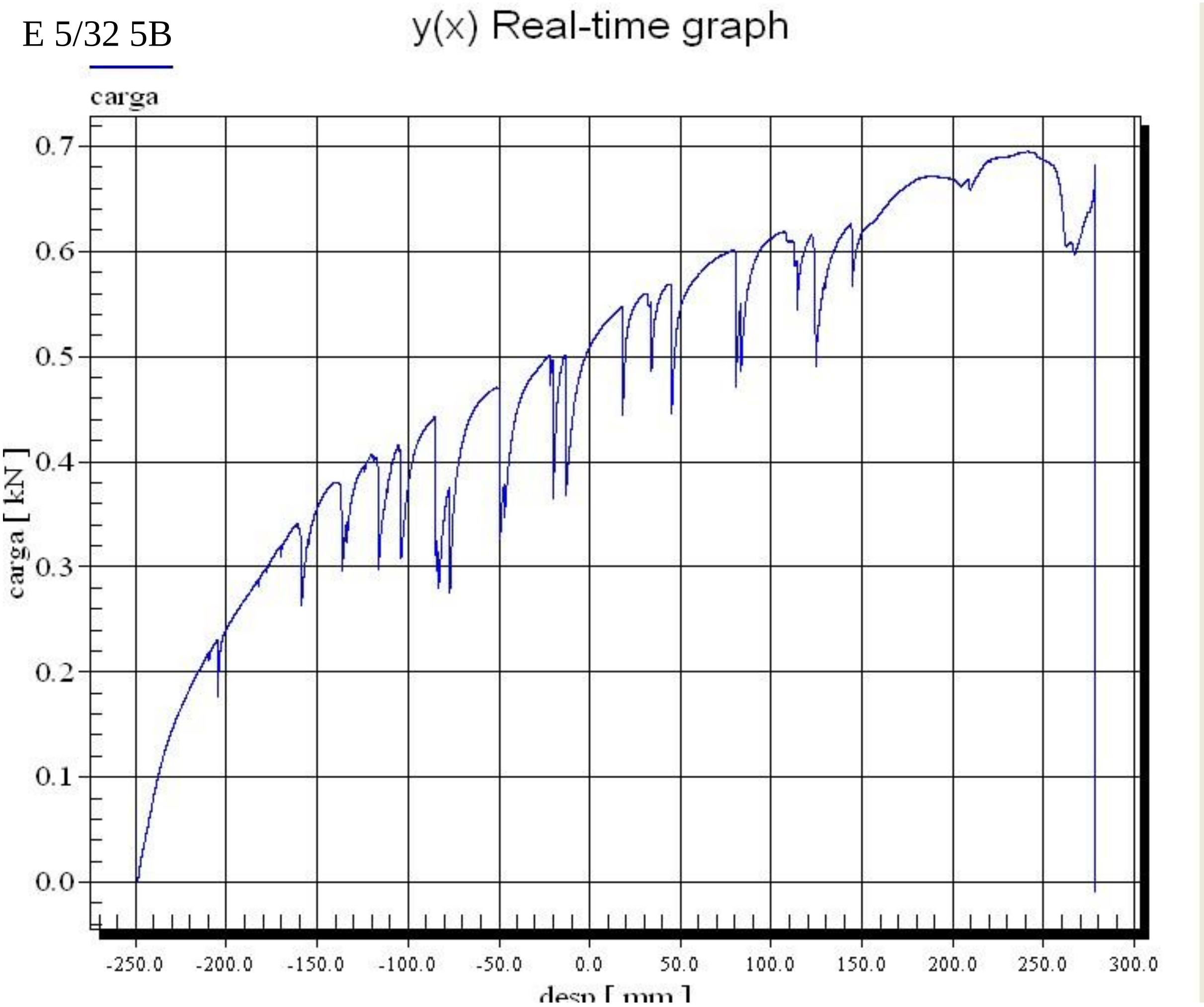
E 5/32 4C

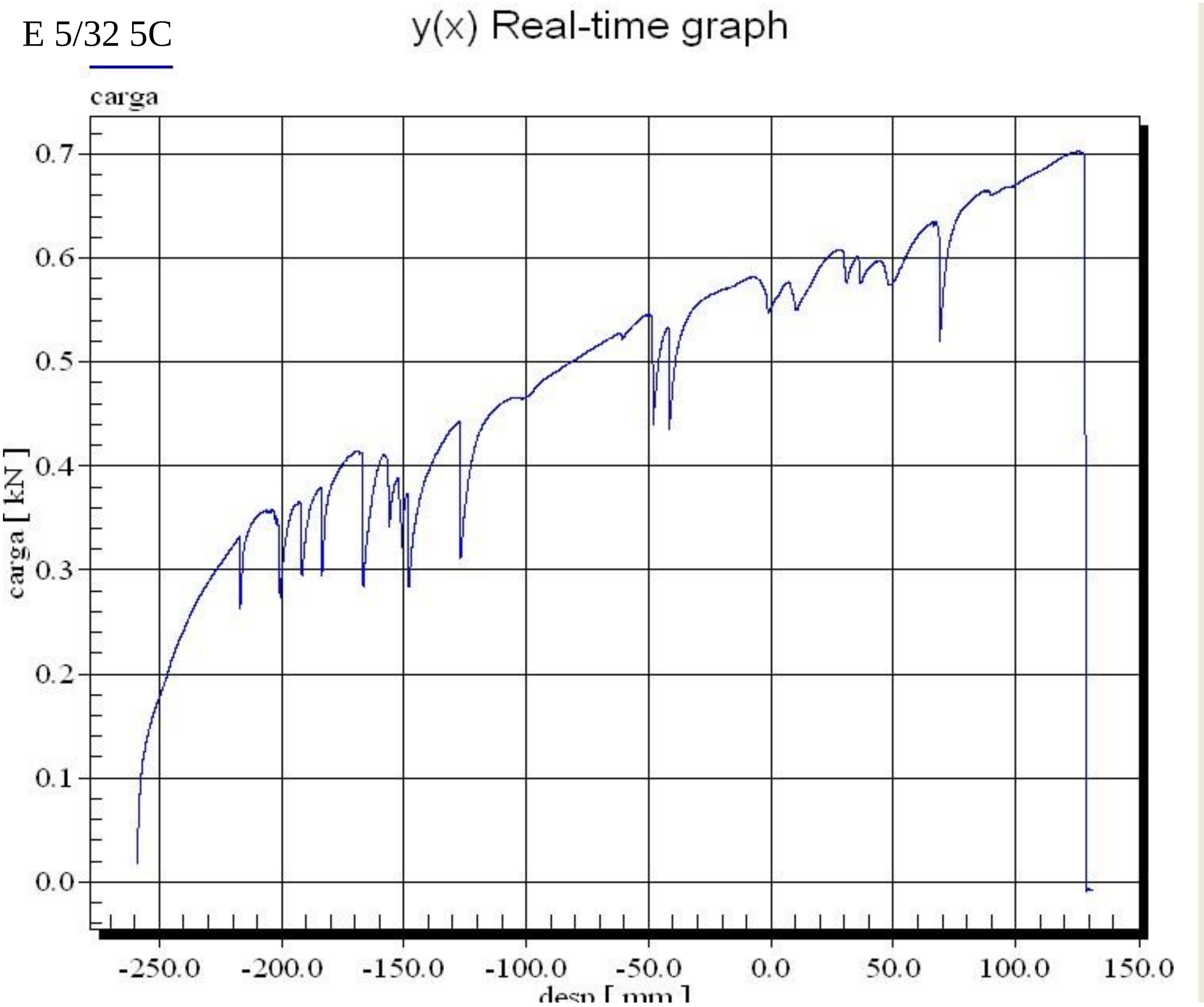

y(x) Real-time graph
carga
carga [kN]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
desp [mm]

E 5/32 5A

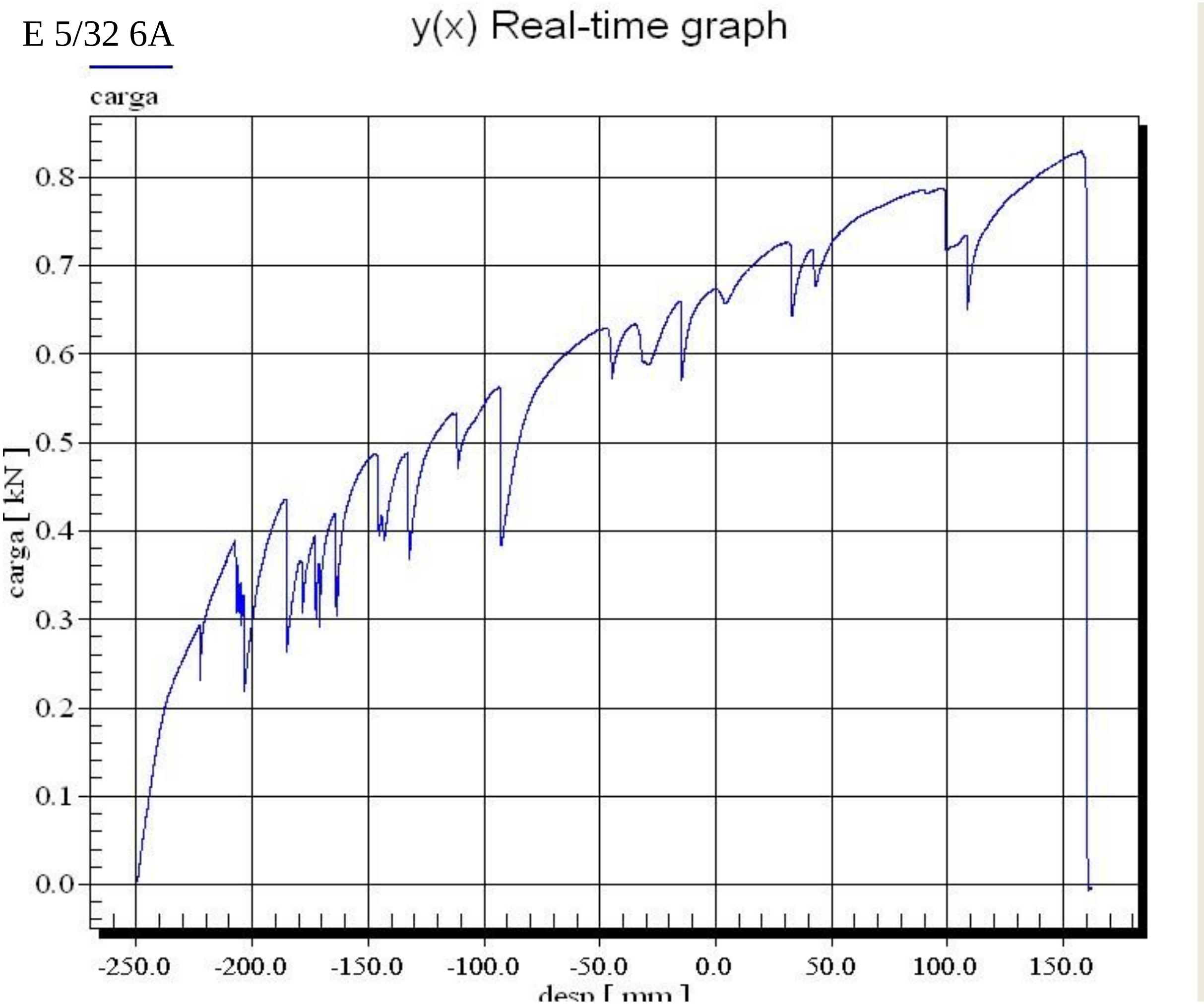


y(x) Real-time graph
carga
carga [kN]
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
200.0

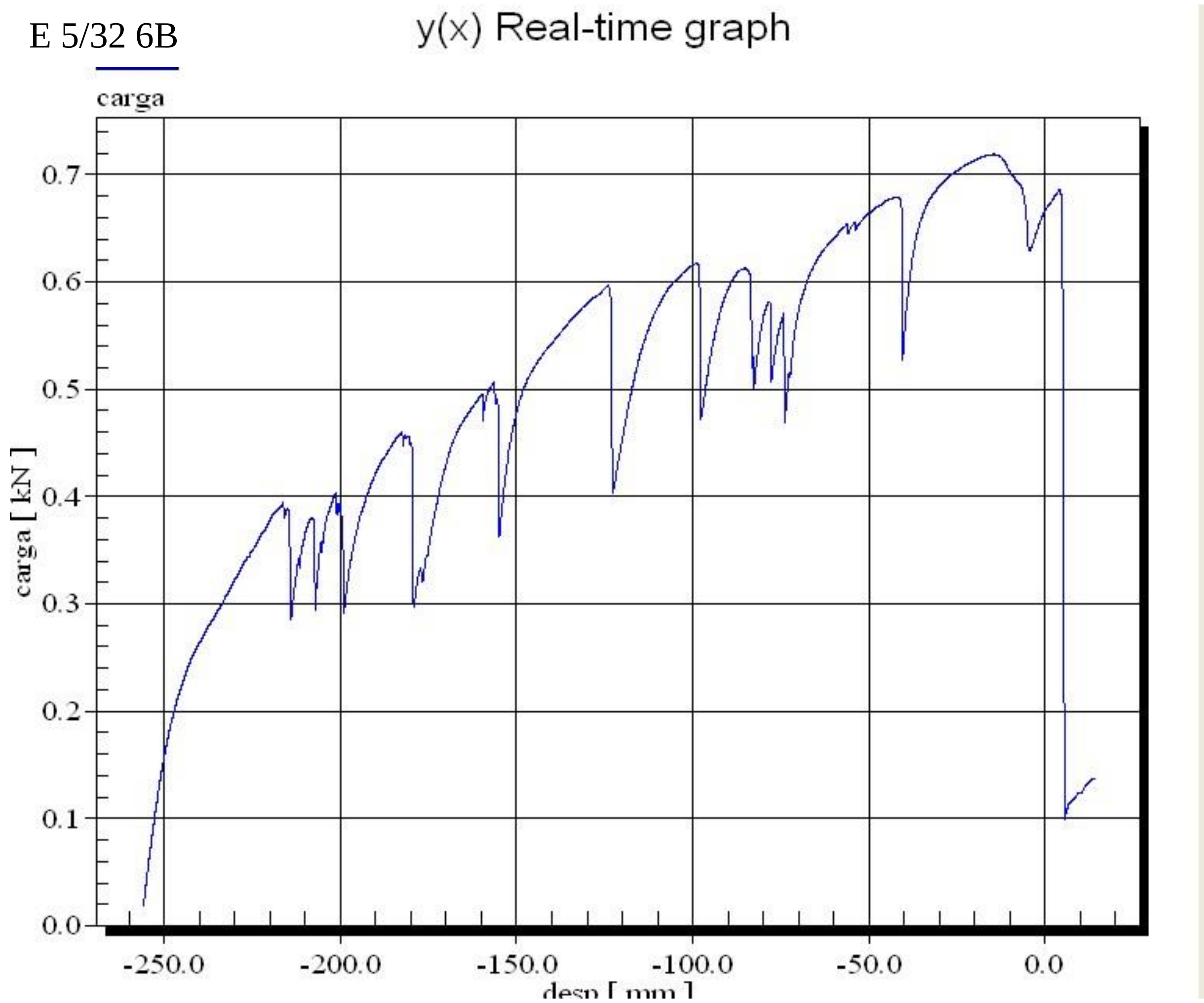

E 5/32 5B
y(x) Real-time graph
carga
carga [kN]
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0


E 5/32 5C
y(x) Real-time graph
carga
carga [kN]
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
desp [mm]

E 5/32 6A

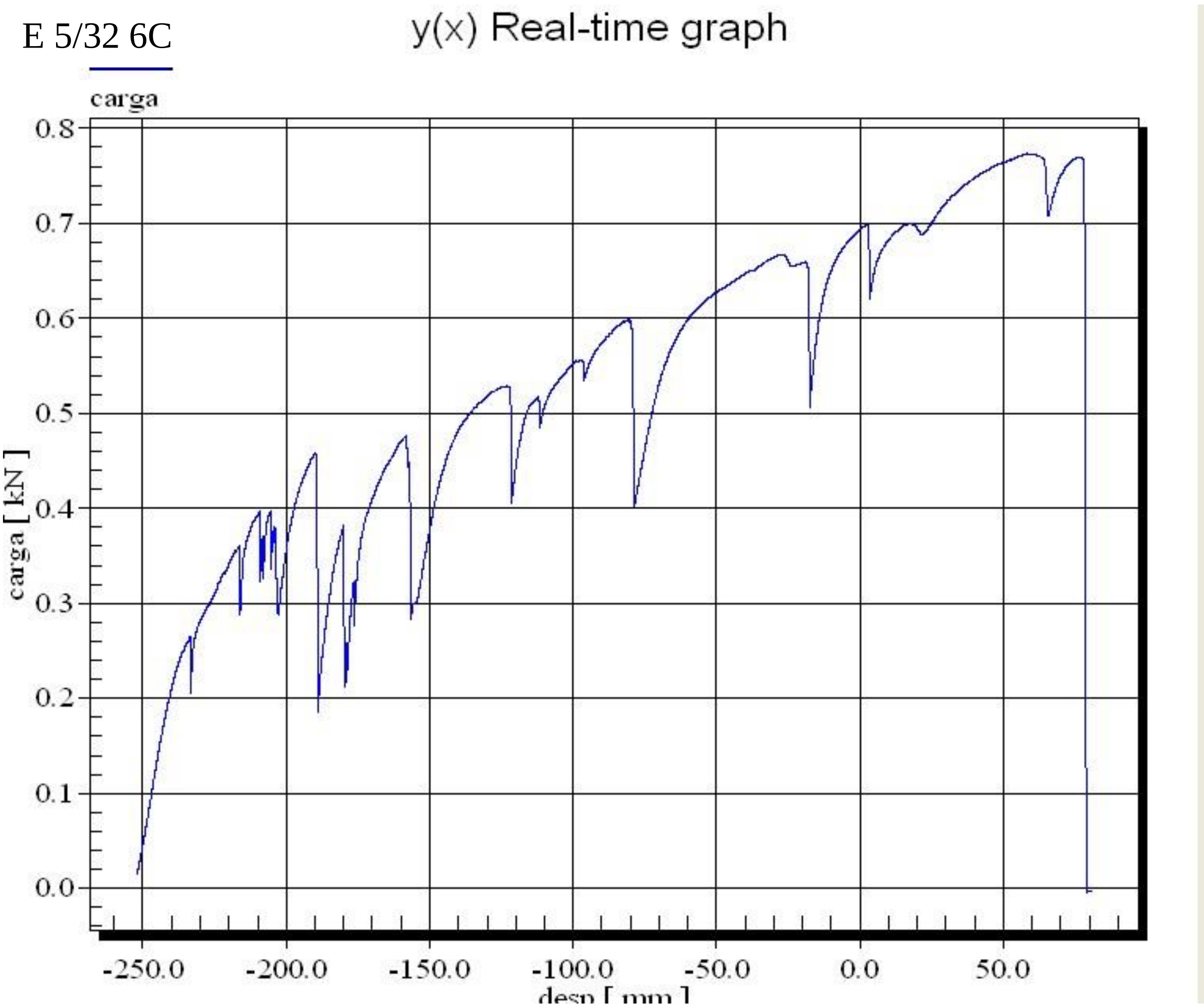

y(x) Real-time graph
carga
carga [kN]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0

E 5/32 6B



y(x) Real-time graph
carga
carga [kN]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
desp [mm]

E 5/32 6C


y(x) Real-time graph
carga
carga [kN]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0

APPENDIX B

The sheets were brought to field to evaluate construction techniques and condition of public buildings

B.1 Survey sheet- Questions to the families

STUDY OF INFORMAL HOUSING VULNERABILITY
REGION - SIERRA
Servey sheet

Date:	House code:
Construction system:	ADOBE

LOCATION OF THE HOUSE:

STATE : Ayacucho		PROVINCE : Parinacochas	
District: Pullo		RURAL ZONE/URBAN ZONE	
Type of road	Av. Calle Jr. Psje. Carretera	Mz. N° Lote N° Mu Km.	
Name:			

Family:

1. Did you receive technical assistance for the construction of your home?
Comments: ....
....

2. Who participated in the construction of your home?
....

3. Did you use plans for the construction of your house?

4. planes were respected during construction?
Comentarios:
....

5. Date of commencement of construction: .... **Date of completion:** ....

Residence time in the house: ....

Currently No. floors: .... **Number of projected floors:** ....

Condition of the house: Bueno ( ) Regular ( ) Malo ( )

6. Sequence of building environments:
Paredes límites ( ). Sala-Comedor ( ). Dormitorio 1 ( ). Dormitorio 2 ( ).
Cocina ( ). Baño ( ). Todo a la vez ( ). Primero un cuarto ( ). Otros: ....

7. How much has been invested in the construction of your home? ....
....

8. What natural hazards affect your home? Sismo Inundación
Deslizamiento Huayco Volcanico Otro: ....

What damage suffered his house? ....
....

9. At present what you consider natural hazards. They could affect your home?

B.2 Survey sheet- Technical data

Technical data

Housing enviroment	Location (Apple)		Pending			Description
	( )	Isolated	( ) High	( )	Filled	
	( )	Intermedia	( ) Mediu	( )	Valley	
	( )	Corner	( ) Low	( )	Riverbed	
				( )	Terr. cultivo	

Charateristics of the soil			Description
	( )	Ridgid	
	( )	Medium	
	( )	Flexible	

Characteristics of major elements of housing					
Element	**Characteristics**				**Observation**
Foundation and plinth (m)	**Foundation (vot)**		**Plinth (sockel)**		
	Material :		Material :		
	Section (bxh)		Section (bxh)		
Muros (wall) (cm)	Adobe				
	Fabric		Fabric		
	Dimens. (bxhxl)		Dimens. (bxhxl)		
	Joints (e)		Joints (e)		
	Mortar		Mortar		
	Cover		Cover		
	Adobe				
	Dimens. (bxhxl)		Dimens. (bxhxl)		
	Joints (e)		Joints (e)		
	Mortar		Mortar		
	Cover		Cover		
System of joists (bjälklag) (m)	Felixible diafragma				
	Type		Type		
	Height (h)		Height (h)		
Ceiling (m)	Diafragma flexible				
	Type				
	Height (h)				
	mpano (under sadelta		Coverage		
	Material : Adobe		Material :		
	Height (h)		Aguas	1( ) 4( )	
Collar bream (m)	Material :				
	Dimens. (bxlxh)				
Beam (under ceiling or joists) (m)	Material :				
	Dimens. (bxlxh)				
Lintels (m)	Material :				
	Dimens. (bxlxh)				
Buttresses (m)	Material :				
	Dimens. (bxlxh)				
Seperation of adjacent houses	Left (cm)				
	Right (cm)				
Seperation of fences	Patio (cm)				
	Garden (cm)				

APPENDIX C

Following posters were posted on wall and used as flyers to get the attention of the audience in the workshop performed in Pullo.

Page 1

Page 2

Page 3

¡Las casas de adobe SÍ pueden ser sismorresistentes!
La PUCP estudia técnicas de refuerzo en su laboratorio.
El más reciente e innovador es el refuerzo con malla de cuerdas.

Ensayo sísmico en la PUCP de un módulo reforzado con malla de cuerdas.

Page 4

En noviembre, un equipo interdisciplinario vino a Pullo para evaluar el daño producido por el sismo y ver en qué podía ayudar la PUCP.

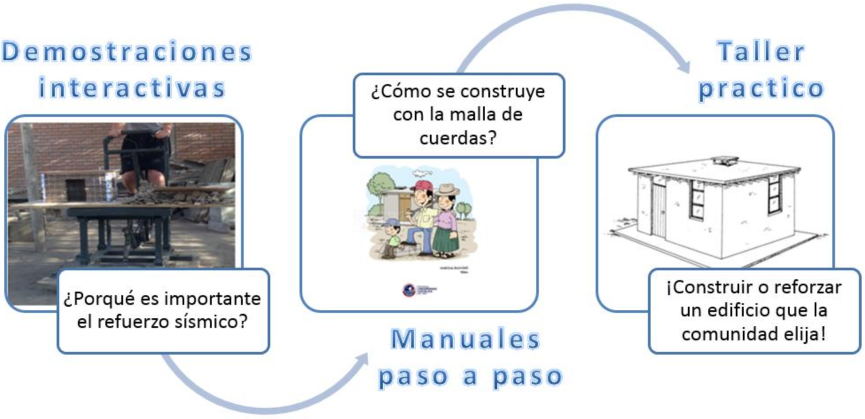
Preguntamos:

¿Cómo era Pullo antes y durante del sismo? ¿Cómo desean que sea Pullo?

También visitamos casas para evaluar el daño sísmico.

Page 5

El taller de capacitación que proponemos para Pullo abarca:



Page 6

¡Con la capacitación aprenderá a construir una vivienda de adobe más segura!

PONTIFICIA UNIVERSIDAD CATÓLICA DEL PERÚ

DIRECCIÓN ACADÉMICA DE RESPONSABILIDAD SOCIAL

CO-LABORAR