Shock Safe Nepal

Team 6

An analysis of compressive strength development in CSEB and optimizing testing methods

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Foreword

In April 2015 Nepal was hit by a sequence of earthquakes of large magnitudes. The epicentre was located close to the capital Kathmandu and had a disastrous effect on the entire country. The capital has since recovered quite well compared to the less accessible villages, as it had first priority to be rebuilt. In the city the damage was limited as there is quite some knowledge on seismic designs and enough money to invest in proper building materials and contractors. However, most of the country is still visibly scarred from the earthquake. Most of the Nepali live in villages in the south close to India. These often remote villages have limited resources and are therefore still recovering from the earthquake. Even more important for the reconstruction, they do not have the acquired knowledge or finances to anticipate on future seismic events. Which, due to Nepal's position on the fault line between two large tectonic plates, is inevitable to happen.

Following the initiative of Cas de Stoppelaar, the Consul General of Nepal to the Netherlands, TU Delft commenced the multidisciplinary student program "Shock Safe Nepal" – a program that allows engineering students of any specialty to apply and expand TU Delft's research on earthquakes and earthquake safe constructions through field and volunteer work in disaster areas.
We are the sixth group of students that have been to Nepal in which we build on the knowledge of previous teams and of the contacts that have made in the past years.

Acknowledgements & Partners

We are grateful for the involved organisations and people for their help and time in the making of this project. Without their help this project would not have been possible.

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Finally, we would like to thank Build up Nepal, Students4Sustainability and FIS fund for their financial support.

DISCLAIMER

This report and its outcomes reflect the work of TU Delft students carried out during and as a partial fulfillment of their study programme. It is in this context that the results should be read and interpreted, and that the academic board has read and graded the work. The students are not yet graduated engineers, so the outcomes need to be seen in this perspective.
Application of any the results in real projects in Nepal is only advisable after a thorough check and validation with proper seismic assessment methods under responsibility of experienced engineers.

Table of contents

1. Executive Summary

After the earthquake in 2015 that struck Nepal, students of the Delft University of Technology commenced the multidisciplinary project program "Shock Safe Nepal". This report describes the effort of the sixth group of students who travelled to Nepal. Where the group built on the knowledge of previous teams and of the contacts that have been made in the past years.

Team 5 has made a technical validation and optimization of the pilot house which was built by team 4. This included analysis of the used materials in the pilot house and a (quasi) static analysis of the house based on the roof, bearing structure and foundation. Team 5 has observed major differences in the properties of Compressed Stabilised Earth Bricks (CSEB). Altogether, they recommended a more specific scope for future teams to make more in-depth research possible.

Following conclusions and specific recommendations of Team 5, the present research has one main goal. This research focuses on improving the overall quality of CSEB and making sure that the final strength of the bricks is constant. This is done by predicting the final strength of CSEB during the early curing stage and using this knowledge to develop a testing method, so the Nepali can monitor the CSEB quality easily and accurately on site in an early production stage. The secondary goal was to perform a dynamic seismic analysis of the pilot house in Ratankot and to get a better understanding of earthquake engineering in Nepal.

To predict the final strength of CSEB, a research into the existence of a drying/hardening curve was performed. Different regions in Nepal ask for different CSEB mixtures because of differences in humidity, temperature, altitude and soil consistency. The biggest influence of the change in hardening process is presumably the cement percentage and therefore also the water/cement ratio. In the Nepali practice this percentage is between 5 and 15 percent, depending on local soil type. Therefore, in this research all soil parameters were kept constant except cement percentages, they range from 5 till 15 percent. Firstly, bricks with cement percentages of 5, 7.5, 10, 12.5 and 15 percent were manufactured under supervision. To develop a hardening curve, bricks were tested after 5, 8, 14, 21 and 28 days. This was done using a (calibrated) compression machine. Results of these tests showed wide spread. Within the first days, the 5, 7.5 and even the 10 percent bricks hardly didn't show any strength gain. They were still too muddy to get usable results from the compression test. However, the 12.5 and 15 percent bricks did show a strength gain comparable to the well-known concrete hardening curve. This behaviour continued, until the 21 days, which is the moment when the curing of the bricks stopped. The final strength was tested after 28 days, with one full week of drying. However, after 28 days the tests showed a sudden gain in strength. The tested bricks were still moist and it was decided to test the CSEB after 38 days as well. This resulted in an even bigger gain in strength such that the bricks after 38 days were twice the strength of the bricks after 28 days.

General conclusion can be drawn that the time period between the curing and testing of the brick makes a significant difference in the results, so this has to be monitored accurately. Furthermore continued curing does not necessarily contribute to the strength of the bricks or might even have a negative effect.

Results from the compression test showed that the general quality, and thus compression strength, of the bricks was lacking. Only bricks with 15% cement surpass the minimum strength of 3.50 MPa after 38 days. This showed that production site was not working properly, therefor Build Up Nepal was informed. This lack of strength is probably caused by a change in variables. The weather in the winter is very different than in summer, but the curing process wasn't modified. Also the soil composition differs every time new soil is brought to the site, which can change the strength drastically.

While researching the hardening curves for CSEB, an alternative testing method was developed. Multiple ideas have been tested, such as a torque wrench with vice, a drop test and finally a lever arm test. The first two methods were deemed unusable as they broke down or were not able to produce reliable results. The lever arm test was most promising as this method produced constant results. Against expectations, the strength of the bricks tested by the lever arm tested was much higher than the strength of the bricks tested with the compression tester. This indicated that not exactly the same properties were measured. The results cannot be directly compared to each other. Therefore a factor should be determined to convert the results from the lever arm to a compressive strength.

From literature it is known that a factor can be used to convert the tensile splitting strength to a compressive strength for concrete. Concluded in a later stage of the research, the lever arm test works as a tensile splitting test and thus the results could be related. Before the method can be implemented there is more research necessary about which property is tested with the lever arm and the converting factor.

Shock Safe Nepal had questions about the level of earthquake engineering in Nepal. Would it be under the European Standard as the education level is lower or would it be higher since Nepal is one of the most seismic active countries in the world. A visit to the National Society of Earthquake Technology showed a very high level of earthquake engineering. They perform numerous analysis on traditional houses and how to improve their seismic capacity. However they do not publish their findings in scientific detail. They, in collaboration with the government have developed a design catalogue. If the guidelines are followed correctly the government funds the project through subsidies. Thus ensuring proper design choices and execution without troubling the average Nepali with difficult technical issues.

One of the greatest difficulty at the moment, learned in a monthly HRRP meeting, is how to communicate this clearly to the Nepali, especially in rural areas. Internet is not a reliable or accessible source and most information is spread by word of mouth.

2. Introduction Shock Safe Nepal

2.1 Problem definition SSN

Large part of the Nepali population lives in rural areas, which have very few expedients and poor accessibility, are still recovering from the April 2015 earthquake. Little knowledge and expertise regarding the (re)construction of earthquake safe housing and the lack of resources resulted in total devastation and limited rebuilding. There is also a limited amount of centralized and organized aid at their disposal as governmental aid is very poor. Furthermore it is inevitable that new earthquakes will occur creating a problematic scene.

This project aims to rebuild the rural areas of Nepal, in such a way that the houses will be shock safe and that the Nepali people are supported in the development of their country. Shock Safe Nepal strives towards a sustainable reconstruction of Nepal and achieves this by closing the gap between knowledge on earthquake safe construction and the people of Nepal.

2.2 Previous teams

Team 1
The first team of Shock Safe Nepal went to Nepal in September and October 2015, in which a thorough analysis of the local context was performed. A systematic documentation of the current state of affairs in post-disaster Nepal was derived. Maybe more important, a the relationship between different degrees of urbanisation in Nepal and the severity of the situation and extent of the damage was found. This led them to a classification of five different regions, from dense urban environments to remote rural settlements, each with its unique challenges that need to be tackled to achieve the goals of Shock Safe Nepal. The first team also investigated different building methods, which could help Nepal in the reconstruction. These methods are to be further examined by future groups. Other focus points include, a more in depth architectural research, a structural analysis and a feasibility study. These points are essential in order to come up with a final concept.

Team 2
The second team was in Nepal in February and March 2016. They focused on the rural areas of Nepal and came up with a strategic action plan, a reconstruction proposal and an education strategy for these areas. First, a strategic action plan which states how the rebuilding of Nepal should look like, in which people are educated and change their mind set towards earthquake resistant building. This action plan is for the short term, midterm and long term, in order to have a sustainable and safe rural Nepal in the end.
Secondly, The reconstruction proposal is both a short term repair plan and a reconstruction manual. In this proposal a typical Ratankot home is analysed on how it can be modified for new and existing constructions, both in accordance with the Nepali building code.
At last, a strategy for education about technical matters which help to decrease the knowledge gap between seismic theory and practice in Nepal. The recommendations for the future Nepal teams are, firstly, that the new team focuses on the rural areas, which are most heavily affected by the earthquake. Secondly, to make a solutions adaptable to different conditions. Thirdly, to work together with major stakeholders such as NRA, DUDBC, NSET, IOM, Kathmandu University, Abari, UN-Habitat, ICCO or other influential parties.

These can provide practical, logistic, legal, financial and localised knowledge and help which are all highly needed. Furthermore, the finances of the research need to be worked out and at last, the key findings need to be updated for future research.

Team 3

The third team of Shock Safe Nepal continued on the work of the previous teams, but focused on a specific project in Ratankot, where they aimed to realize earthquake resistant housing. An analysis of the rules and regulations given by the Government of Nepal specific to the village has been made. Combined with the designed reconstruction, a demolition and waste management plan is developed. After this, they performed a multi criteria analysis on approved building methods by the Government of Nepal. From this analysis three different housing designs (and main construction materials) were viable for future research and design:

- Stone masonry; the most common technique in rural Nepal, so acceptance by the population will be less of a problem.
- Wattle and daub with rammed earth columns; only one floor so it's safer, local materials used so limited transport costs.
- Compressed Stabilised Earth Bricks (CSEB); a lot like masonry but has the advantage of local production with local resources. This saves costs and helps build local economic activities.

The funding of the government is not enough to reconstruct the same size house as before, therefore the designs have an incremental component built in. The basic house can thus be expanded afterwards.

Team 4

Team 4 focused on the implementation of the design of team 3 in the test case village Ratankot, while in the same time the possibilities were explored to generalize this concept for the other villages in Nepal. They build a pilot house of the third design of team 3, which is the CSEB house. In order to generalize the concept, a modular version was designed to be applied in the various villages of Nepal, hereby considering the governance structure, logistical challenges, economic feasibility and specific local requirements. At last the network of partners which is build up by the previous teams, both in the Netherlands as in Nepal was maintained, which is necessary for a successful collaboration.

Team 5

The goal of the fifth team was to validate the pilot house which was made and making a long term plan for sustainable upscaling of earthquake resilient housing in rural areas in Nepal. First the validation and optimization of the pilot house has been researched with respect to the design, dimensions and the structural behaviour of the house. This includes an analysis of the used materials in the pilot house and a (quasi) static analysis of the house based on the roof, bearing structure and foundation.

Secondly, the long term plan is reviewed based on:

- Stakeholders who are related to the project when upscaling the design.
- External factors which are important (social, technical, environmental, economic, political, legal and ethical) → STEEPLE & Safety.
- A case study on organizations who are currently rebuilding Nepal.
- A SWOT/TOWS analysis has been done and a risk assessment has been executed.

Recommendations for future teams is to further validate the house based on the structure, soil, locations and need to perform more (quasi) static test. Also a material analysis has to be further developed, and these materials have to be consistent as well. Team 5 has seen major differences in the properties of CSEB. The future teams need a specific scope, which result in more in-depth results, which will improve the overall quality of the houses made.

3. Scope

We are the sixth group of people that is going to Nepal to perform research. The previous teams have gathered information on how the country is recovering from the earthquake together with the structural and social challenges that come with it. The first teams worked on research after which research phase designs were made to suit the habits, materials and capabilities locally. A pilot house was built in Ratankot by members of team four. In the figure below the pilot house is shown, made of Compressed Stabilised Earth Bricks (CSEB), concrete and bamboo.

However, this house was built before the structural design was thoroughly checked. Therefore, the previous team has tried to research its structural capacity, but this was only possible to some extent. The seam has encountered several setbacks. Firstly, to validate the house regarding earthquake resilience, the team had to make extremely difficult calculations. To make these dynamic structural calculations for a group of students in such limited time, turned out to be too much to ask. Instead of these dynamic calculations, the team made static and quasi-static calculations.

The second major problem was that in order to make structural calculations to verify the safety of the house, characteristics of the used materials must be known. Generally, these can be assumed with a reasonable margin of error. However, looking at the state of materials and the construction process which was analysed these material characteristic shouldn't be assumed. To proceed with the validation

Figure 1: Team 6 with Shyam in front of the pilot house in Ratankot

purpose, material properties needed to be gathered and analysed. (Shock Safe Nepal Team 5 Final Report, 2017). It also became clear that no governmental help or funding is available or is not compatible with the less resourceful villages. The actual design and verification of an earthquake-proof building suited to the living standards of the Nepali was a plan which now seems not the most ideal goal, since the knowledge and time spend by students during a multi-disciplinary project is limited. Therefore Shock Safe Nepal can create more impact by focussing on a more specific part of the whole earthquake proof building.

The future view and recommendations of team 5 are summarised in their report as follows: "The research that has been conducted in Nepal, by SSN team 5, was relatively broad. To gain more in-depth results and creating a greater impact, a more specific scope should be applied in the future. Meaning a choice on a specific subject. Examples of this are an in-depth research on CSEB, quasi-static research on the foundation or walls and/or tests on the soil. It has become more important for Shock Safe Nepal to gain more specific and detailed information on different topics. To achieve this in a structured way, limiting the scope for a project should receive more attention than it should generally have for a project, due to the severe and life threatening nature of earthquake safe building." (Shock Safe Nepal Team 5 Final Report, 2017)

With the information gathered from previous teams, a different approach is needed. Still lots of houses which are being built in Nepal are not earthquake resilient, which means there are still enough challenges to overcome and opportunities to help. The lack of resourcefulness of the government for the remote villages is something that requires attention, but fortunately there are many organizations, who are helping those people living in these areas. Most of these organizations can improve a lot with the help of students which bring academic skills and research. A collaboration between such an organization and Shock Safe Nepal can lead to relevant results which can be put in practice by the organization, they can also and make a difference since the resources of the organization will be used. There will be enough people working throughout the country and there will be no time gap between teams. Although research is done well on cultural and social challenges nothing beats the knowledge of people who work and live in Nepal for a longer period of time.

Build Up Nepal is such organization, they are "specialized on rebuilding rural villages with Earth Bricks & efficient stone cutting. They offer help with construction, building small business and long-term village development." (website Build Up Nepal, https://www.buildupnepal.com/about-us/).

They have been enthusiastic about Shock Safe Nepal the past years and both interest seem to marry well. Build Up Nepal is striving in improving the quality of CSEB, therefor it needs research, which Shock Safe Nepal can perform. They will supply the team with all the required facilities for the research.

The discussion part of the report of SSN 5 states: "The material analysis in this report, regarding bamboo, steel and CSEB, are mainly based on sources and laboratory tests done by other researchers with limited documentation of the test setup. It shows limited information and results in less credible assumptions and decisions regarding the materials used in Ratankot. Therefore, laboratory tests using the materials from Ratankot should have been conducted for comparisons and more credible results." (Shock Safe Nepal Team 5 Final Report, 2017). Along with the advice of team 5 to really narrow down our scope, as opposed to their (far to) wide scope, the further research on CSEB seems like a logical next step. The development of an alternative cheaper building material then used traditionally is a crucial step in the rebuilding of Nepal. When material is cheaper more resources can be put in other factors improving the structural design. In some areas Nepali can get funding from the government to build a certain type of house within a certain price range. These bricks have the potential to enable the more remote villages to also make use of this since the bricks can be made locally and no expensive pre-made traditional bricks or cut stone have to be imported.

Build Up Nepal has already made several improvements in the process and can now build houses in ten days using their technique. However, quality can and needs be improved. They stated that the use of new materials is not quite liked by the Nepali. Innovative ideas have failed in the past, as their quality was not up to the required standards before using it. This resulted in a lack of faith in new materials by the locals. The challenge to ensure quality of a material made by locals without expertise (though they are now supervised) is something that is demanded.

Shock Safe Nepal and Build Up Nepal believe this collaboration is very well suited to serve both our goals in Nepal. In the next chapter this scope will be elaborated by the set goals.

4. Goal

After the results of the previous team were evaluated and several skype meeting were held with Build Up Nepal, the conclusion was made, that the quality of CSEB at the building sites of Build Up Nepal are not constant. This is one of the reasons why it is difficult to determine the earthquake resilience of the bricks. Therefore it is important that more research is conducted on CSEB.

The main goal of this research is to improve the overall quality of CSEB, and make sure that the final strength of the bricks are constant. The main problem of the earth bricks is the variance in quality, this could results in houses of insufficient strength, which may not be as strong as calculated and could have disastrous effects during an earthquake.

The second goal is to develop a testing method, which is cheap, fast and easy, to predict the final strength, so that the people in the rural areas can test their own bricks. The quality of the bricks are now determined 28 days after the brick are made. When the CSEB is not strong enough all the bricks in that batch cannot be used, and possibly also the bricks which are produced and are still being cured. When the Nepali people have a testing method in which the final strength of the brick can be produced it can save a lot of time and money. The testing machine has to be cheap, because the people themselves need to purchase the testing device. It needs to be fast and easy as well, otherwise the testing method is to much of a hassle, in order for the people to use it, in which it won't make an impact. To summarize the determinative factors of this method, Björn Söderberg, managing director of Build Up Nepal said: "It has to be under a 100 dollars and the test must be able to perform the test within 5 minutes, otherwise it won't be used."

With the results of the research, new information about the CSEB is available, which can be used to get a better understanding regarding the behaviour of the pilot house during an earthquake. The previous team also worked on this validation of the pilot house, but due to a lack of information about properties of the CSEB, they couldn't continue. Validating the house regarding the earthquake behaviour is the third goal of this research. The research will determine whether the seismic design needs improvements. However the first two goals will be the priority, since a seismic analysis can cost a lot of time.

The last goal is to ensure the continuity of Shock Safe Nepal as a project. This is a general goal for all the teams, in which the teams maintain the relations, which previous teams have set up. The plan is to set up meetings with these relations in which possibilities for future teams are discussed. In the future other research topics could more demanded, involving other parties than Build Up Nepal, the main partner for this research. This will make the construction of proposals of future teams easier. By having these meetings with other parties, it is important to keep the greater picture of the project in mind, and know how the reconstruction of Nepal is going. This is important, because this research is fully focussing on CSEB. Most of the time spend will be with Build Up Nepal, which is only a small part of the reconstruction in Nepal.

5. Background Build up Nepal & CSEB

Build Up Nepal is an NGO founded by Björn Söderberg after the devastating earthquake in 2015. In the first project of Build Up Nepal they built six bamboo houses for single mothers in Majigaun, a small village just outside the Kathmandu valley, about 4 hour drive. Bamboo is a promising building material, it can be found locally in Nepal and has good material properties for earthquake resistant building. The bamboo is hidden under the plaster walls of the house. After 2 years these houses are still in really good shape and although Build up Nepal gave training and lessons on how to build the houses during the construction, the rebuilding of the village didn’t go as planned. This is because bamboo has a bad reputation as a building material. Bamboo is seen as the building material for the poor, because it rots away when the material is not treated. Even after showing people that the house will not rot away after treatment the Nepali are not enthusiastic about this way of building. The result is that the Nepali people are not building their own house out of bamboo, like in Majigaun.

This forced Build Up Nepal to look for other building designs, in which they started using CSEB. The Nepali dream is to have a house made out of bricks, fortunately the CSEB are seen by the Nepali as bricks so the reputation of the material is good.

The previous team stated in their report that they have built 38 houses out of CSEB. Right now they are active in over 70 building sites throughout Nepal. They believe the best way to rebuild Nepal is by empowering local people and using local materials. Together with INGOs and NGOs they provide machines and training for rural communities, teaching them to make Earth bricks (CSEB) and rebuild their own village. Their goal is to make the people more independent, by letting them build their own house, they are giving them responsibility and therefore also promoting local entrepreneurship. When team 5 was in Nepal, the CSEB was not yet present in the Nepal Building Code (NBC), luckily in late 2017 the CSEB was included in the NBC. A major breakthrough for Build Up Nepal, since they were already working with this type of bricks, they had an advantage in skill and knowledge. Houses are now being built with grants from the government, which means that funds from organizations are not necessary anymore. This is resulting in an enormous increase in demand for the CSEB housing. Right now there is a big shortage of skilled people at Build up Nepal, and also a huge demand for research. Since everyone is working so hard giving training, building new houses, there is not so much time to check the quality of the bricks and improving the methods used.

The CSEB is a made from local materials, it is a mixture of sand soil silt gravel with cement and water. In poor accessible areas the bricks are mostly made on site, this is because the transportation costs are high in Nepal. Only cement is transported to these places and sand soil silt and gravel are gathered locally.

On site the people are given a week of training, most of the time the most skilled men and women are selected. They are given the responsibility to manage the building of the houses. In this week of training they learn how get to the right mixture, press the bricks, dry the bricks and cure them. Also the foundation, the first layers of CSEB are being made and the reinforcement bars are put into place.

6. Research questions

To reach the three goals of this project, three research questions have to be answered. The first goal is a result from the theoretical research which needs to be performed, a requirement from the Delft University of Technology. The second goal focusses on the practical aspect, following from the partnership with Build Up Nepal. The last goal is set to work further on the work of the previous team. In which the team worked on validating the design of the pilot house in Ratankot.

The first goal is to predict the final strength of bricks during the early stage. Thus the main research question is as follows:

1. ***How can we predict the final strength of CSEB during the early curing stage?***

To answer the main question, four sub research questions are needed.

1.1. *What properties of CSEB are essential for determining the strength of the earth brick?*

The compressive strength is considered the most important variable by Build Up Nepal. The bricks have to withstand a minimum pressure of 3.5 MPa. This value is stated in the NBC. This means that if the CSEB doesn't meet this requirement, people won't receive a grant from the government.

To have an earthquake resilient building the CSEB has to withstand high tensile and shear stresses, because those stresses build up rapidly during an earthquake. The tensile and shear strength of CSEB can afterwards be calculated by factorising the compressive strength, which can be done with concrete codes.

Testing the compressive strength is most simple and this is the factor which determines whether the brick can be used from the Government.

1.2. *Which elements in the production process determine the final strength of the brick?*

There are several factors, which determine the final strength of the CSEB. The composition of the mixture, the amount of water in the mixture, the amount of material in the press machine, the temperature in which the brick is dried, how the curing is done, and the number of days it is dried and these are not even all factors. To test the composition all units are measured. For the research, two parameters are made variable. The first one is the amount of cement and the second one is the number of curing days to see how the cement percentage influences the compressive strength of the bricks. The other variables are held constant, the brick is weight before tested and checked for inconsistencies.

1.3. *How does the compressive strength of CSEB develop over time?*

If there is a clear relation how the compressive strength develops over time, the strength can be predicted in an early stage. This could save a lot of time and money when a batch with a poor quality is made.

1.4. *At what time during the early stage of the manufacturing process can the final strength be predicted of the CSEB?*

The earlier the final strength can be predicted, the better.

The second goal of the research is to improve the overall quality of the CSEB, and specifically keeping this quality of the constant throughout the building sites. For Build Up Nepal it is important to be able to test the bricks in the early curing stage to see if they are of sufficient quality. In that way they can adjust the production process accordingly. This results in the following second research question.

2. ***How is a fast and cheap CSEB testing method developed, which can be implemented on all building sites of Build Up Nepal?***

The third goal of the research is about applying our knowledge of earthquake engineering on the seismic design of the house.
Research question regarding third goal:

3. ***What is the level of earthquake engineering applied in Nepal and are there guidelines or codes regarding this subject?***

Nepal is a developing country where especially the level of education is of a lower standard then in western or richer countries. Promising Nepali academics therefore often go abroad to India or even further for their education. As a result specialized engineers, such as earthquake engineers, may be rare.
Nepal is situated directly above a fault line between two large tectonic plates moving toward each other creating the Himalaya's together with large earthquakes. In one of the most seismic active area's in the world knowledge about earthquake engineering is expected to be developed.
Both arguments contradict each other and it is interesting and crucial to Shock Safe Nepal to establish the level of knowledge in earthquake technology in Nepal.

7. Execution

7.1 CSEB

7.1.1 Production of CSEB

It is essential to fully control the production of the CSEB. The quantities of materials used during the production of the bricks are known. On site all the quantities and ratios were measured, which makes the research reproducible.

To make the bricks, a measured amount of soil, sand, cement and water is mixed and used. A wheelbarrow and buckets are used to measure the quantities. The ratios in which the materials are mixed depend on the type of soil, which differs at every building site, resulting in earth bricks which have a unique mixture at every site. At this site, which is the place where the earth bricks for the research were produced, Build Up Nepal uses a volume ratio of 3:4:1 respectively for soil, sand and cement. Water is added intuitive by the workers.

The purpose is to set up the hardening/drying curve of the CSEB for different percentages of cement. To exclude all other variables it is important to maintain a constant ratio of sand and soil, as well as the ratio between water and cement.

The step-by-step production of CSEB:

1. Sieving
2. Jar Test
3. Mixing
4. Adding cement and mixing
5. Adding water and mixing
6. Turning mixture into brick
7. Cut off the protruding parts
8. 24 hours hardening
9. Stacking and curing

Tools used for the production:

1. 4 buckets with a volume of 15 L
2. Weight scale
3. Iron cutting plate
4. Wheelbarrow
5. 4 shovels

In the appendix (15.1) all the different steps of production, and quantities used in the process, are elaborated. In Figure 2 an overview can be seen of the building site. In the next pictures several steps in the process are shown.

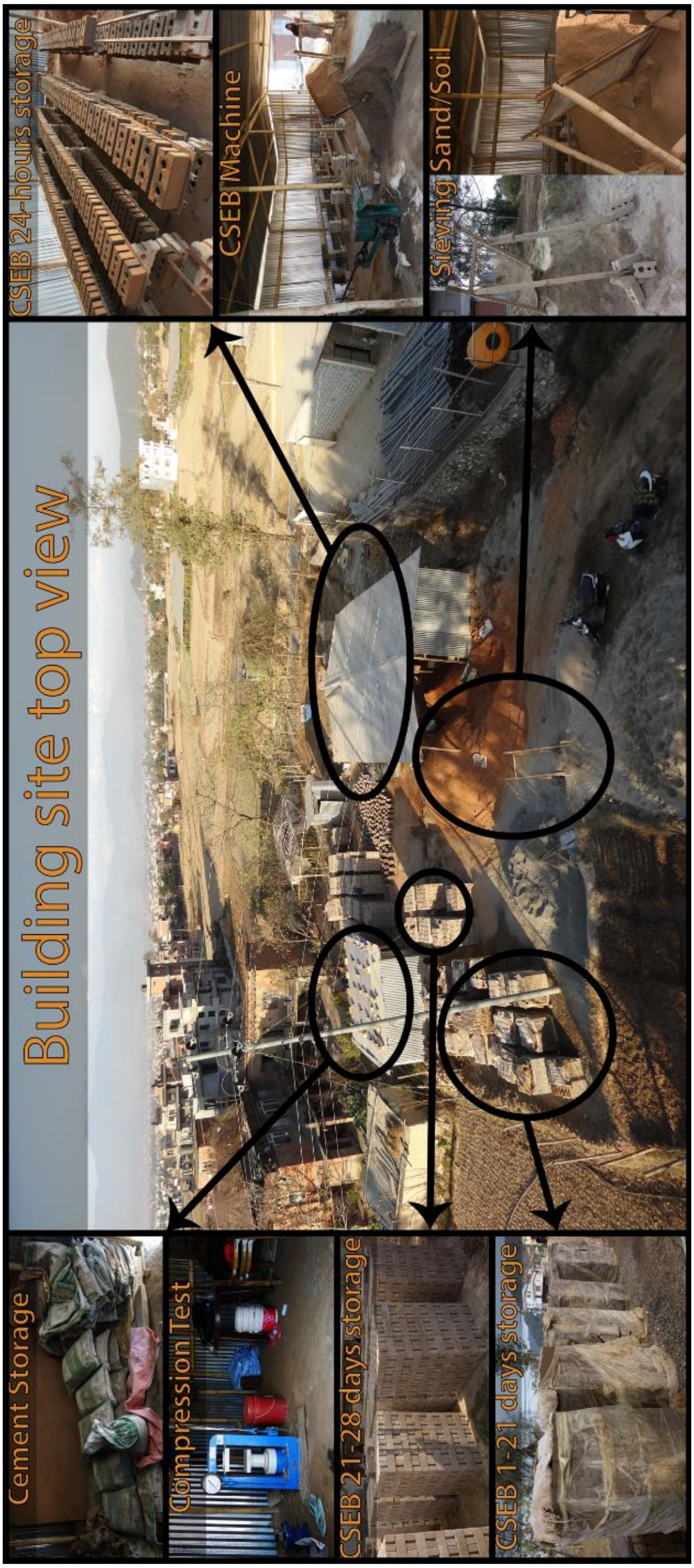

Figure 2: Building site overview

Figure 3: Nepali workers making the drymix for CSEB

Figure 4: Nepali workers putting the mixture in the CSEB press

Figure 5: CSEB storage for 24 hours

Figure 6: CSEB storage for 1-28 days

7.1.2 Testing of CSEB

The aim is to find out if there exists a hardening curve for CSEB such as there is for concrete. If it is possible to obtain this hardening curve the final strength of a brick could be predicted before the usual 28 days of hardening and drying. It is expected that the relation curve between time and compressive strength might not be as significant as it is with concrete. Due to the fact that the curing and drying of the bricks are not in an contained environment, which is the case with concrete. During the whole production and testing of the bricks, the planning had to be adapted several times, which will be explained below.

The initial testing plan was to test the bricks after 2, 5, 7, 14, 28 and 28 (including mortar) days with both the torque wrench (later explained in 7.2.6 Torque wrench and vice) and compression test. The minimum amount of bricks to test from the same composition at one time step is six (CEN-members. (2000). *NEN-EN 772-1)*. With six as a minimum the aim was to make seven bricks for every time step. This was an ambitious plan, which could not be realized. Before the production of CSEB started, the decision was made to decrease the amount of time steps (to four) and increase the amount of bricks tested every time step (to ten). Doing this, the quality of results per time step increases. The insight in the compressive strength in the first week decreases, however due to logistics this was not possible. Fortunately, when a hardening curve for concrete is made the common way of testing it is after 3, 7, 14 and 28 days. Initial ambitions to test the different compositions after 28 days filled with mortar were set aside as the added value to the research would be limited compared to the time it would cost. It would be interesting to see what it would do to the compressive strength of the CSEB. However in the end the CSEB has to withstand 3.5 MPa without being filled with mortar.

Three days after the production of bricks with 5% and 7,5% cement the compression machine was calibrated and the torque wrench installed. Test were executed to make sure the devices were working well. The compression test gave an expected result to assume correct calibration. Unfortunately, in the second torque wrench test, it broke. The node of the thread and the fixed part was distorted which resulted in tearing of the cast iron as can be seen in figure 7**Fout! Verwijzingsbron niet gevonden.**. Furthermore the torque wrench wasn't working properly as the device didn't made a clicking sound. The clicking sound indicates when the set moment is reached. After the incident several possibilities were discussed with the engineers of Build Up Nepal. As the torque wrench and vice did not work in a testing environment it was decided that it probably wouldn't work in practice as well. To buy a new wrench was not an option. A new torque wrench of high quality would be too expensive. Build Up Nepal gave a new assignment: to design a cheap and easy alternative for the torque wrench, like the drop test. See 'Alternative Test Method' for this subject.

Testing with the compression test proceeded according to plan. Both the 5% and 7,5% cement bricks had the same result: the compression tester didn't show a value at point of failure. Another attempt a day later resulted in another value-less result. An explanation could be that there is still a lot of water in the bricks, therefor it acts like a sort of mud rather than a stone. When the device exerts a certain pressure on the bricks there will be a displacement and the pressure in the compression tester cannot build up enough to show any result on the meter.

It was the question after how many days the bricks were hardened enough to give a visible result. Consequently the planning had to be adjusted again. The bricks would be tested after 5, 8, 14 and 28 days with the compression tester only. Along with meter values the amount of strikes put on the stone would be recorded. Later it would then be checked if this was relatable to the force applied. After 28 days the bricks were not fully hardened yet. It was visible the bricks were still wet on the inside and partly on the outside. The remainder of the bricks were tested once more after 38 days in an attempt to obtain full strength. This should be around 98% when at 28 days the bricks already would be dry.

Figure 7: Broken vice

Figure 8: Compression tester

7.2 Development of an alternative testing method

According to the building code of Nepal the CSEB need a minimum compressive strength of 3.5 MPa (Government of Nepal, 2017). This is one of the requirements that should be fulfilled to be rewarded with the grand of the government. More importantly, in our opinion, a strength of 3.5 MPa is needed because the bricks are load-bearing and a weaker material would seem unsafe.

As explained in the Production & Testing of CSEB, all bricks are made with local soil. This is one of the sustainable advantages of the bricks: less material to be transported. However this also results in bricks with a slightly different composition even if production method is identical. Every CSEB of a particular building site is therefore unique.

As the compositions differ the final bricks have to tested at every site for quality control. This ideally can be done on site as transportation is long, expensive and may even influence the strength of the bricks as roads in Nepal are of varying quality, especially the sites in rural areas. The best method to test the bricks is with a compression machine. Only it is too expensive to equip every building site with a compression tester. For this reason there is a need to develop a new test method which is both cheap and easy to perform.

Ideally a test should cost around 10,000 Nepali Rupees (80 euros) and takes less than a minute of time, otherwise it is unlikely to succeed. (Bjorn, Build Up Nepal)

The alternative test method should:

- Give results about the final strength of the CSEB. The test should clarify if the mix of materials is right (ingredients could for example be forgotten or not mixed right)
- Be as cheap and easy as possible. The test device should be below 10,000 Nepali Rupees, the device could then be delivered at the building site together with the production machine. When the machine would cost more money or the testing would take more time in execution it would not be used in practice (source: Build Up Nepal)

Build Up Nepal has come up with different device alternatives of the compression tester together with different organisation such as students from Sweden, Shock Safe Nepal and Auroville. The devices are listed in chronological order:

1. Drop test with mixture
2. Drop test with CSEB
3. Load test
4. 3-Point Bending test
5. Lever arm test
6. Torque wrench & Vice
7. Conventional Compression tester
8. Smaller compression tester
9. Hydraulic bearing press

7.2.1 Drop test with mixture

The drop test for mixture is performed before the mixture is turned into CSEB. The mixture of sand, soil, cement and water is formed into a ball by hand. When a ball is made, it is dropped from a height of 1 meter. When the ball doesn't break into pieces it is too wet, and when it breaks into thousands of pieces it is too dry. Ideally it should break into 3 or 4 pieces (Earth Brick Production Manual, Build up Nepal).

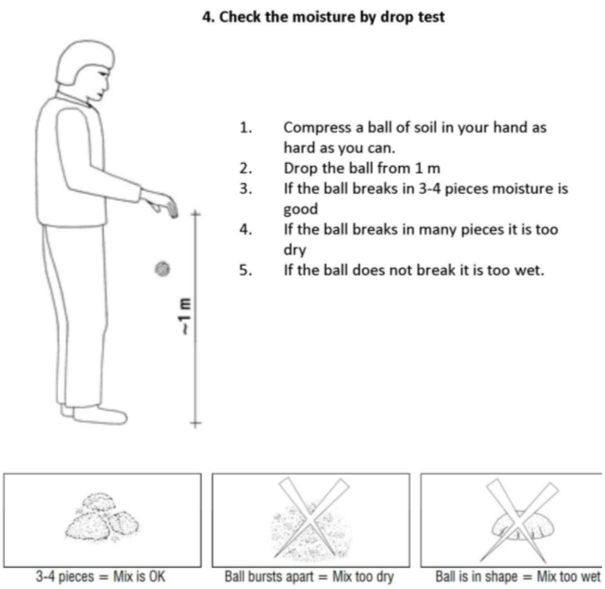

Figure 7: Moisture check by droptest

7.2.2 Drop test

The drop test is a way of testing the CSEB by dropping the brick from a certain height. The brick is held into place by two pillars which fit into the holes of the CSEB, the brick is dropped on a triangular shaped iron plate. When the brick breaks, the "break height" is achieved.

Although the testing method is quite basic, the translation to the compressive strength of the brick is quite difficult. Therefor the impact time and the impact force need to be determined by slow motion videos which were made during testing. Afterwards the impact force needs to be translated into a compressive strength, if possible.

The test might be better suited to tell something about the moisture content or elasticity of the brick. It might not be the best test to say anything about a 'right composition' of the brick, like the ratio of cement, sand and soil as well. Build up Nepal is still not sure about what the drop test is best for, so the goal is to investigate if there is a correlation between the results of the drop test and compressive strength of the bricks.

There expectation of the droptest is that it cannot be related to the compressive strength and that it can only say something about other properties of the brick, which are of less importance in our research. Even if the impact force can be related to compressive strength, it will be extremely difficult to accurately determine these impact forces. There is a chance that a correlation between those properties exist. For example the E-modulus of the brick can be plot against the time and this could be related to the hardening curve.

At the end of the curing time, 28 days, the bricks should resist a drop test of 1,2 m high. (Silva) The force exerted on the brick can be calculated with kinetic energy, momentum and impact time. Therefore the braking time of the brick (the amount of time it takes for the brick to stop moving) is needed. Slow-motion time frames of the drop tests were made to get an idea of this breaking time.

To get the best results for our drop test, the following method was chosen.

Method used in drop tests:
The height of the drop test is found by trial and error because the hardening curve is still unknown at this time in the research. This can be done in the two following ways.

1. Six bricks per cement ratio are tested for all testing days at which the compression test was

also done. The height will be increased after a brick has been dropped, until a height is reached that it breaks, for example 0.5 meter. The CSEB has been weakened by the previous drops. The next brick will be dropped from 0.5 meter and a certain increase in height is gained. This will continue until a height is reached that the CSEB breaks immediately. When the CSEB has not failed, the size of the groove in the brick will be measured every time.

2. Again six bricks are tested of every cement composition for all testing days. The height will be set beforehand. In this approach the number of executions of the drop test before failure is determined. When the brick has not failed after for example 5 times the height could be increased. This test has to be done for all the six bricks to get more insight about the relation between the strength of the brick and breaking height.

Both these approaches are very theoretical. The drop test is a dynamic test and executed by people themselves. Risk of human errors, like not using the exact height or not letting the bricks fall exactly straight down, is very large. This means that the methods are hardly possible to apply because in both approaches the assumption has been made the bricks are about the same.

Figure 8: Droptest with a CSEB brick

7.2.3 Load test

After considering the drop test, which tests other properties of the brick, a load test is considered. The device of the drop test is used differently, instead of dropping the bricks from a certain height, the brick is first placed on the triangle and bricks are stacked on top of the bricks.

Figure 9: Loadtest

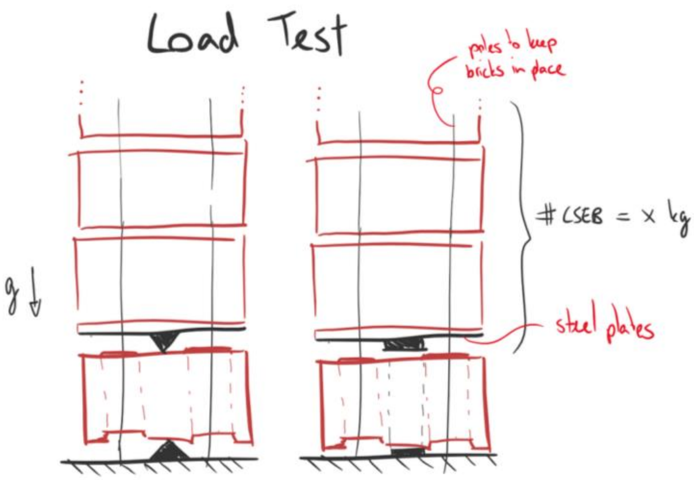

Figure 10: Load test

7.2.4 3-Point bending test

This test was designed by Auroville to test the crushing strength of the CSEB. The weight put on the tester can be translated to the compressive crushing strength. However this device turned out to be not strong enough. When testing the brick, too much weight had to be put on plate, which caused the arm to bend instead of failure of the brick.

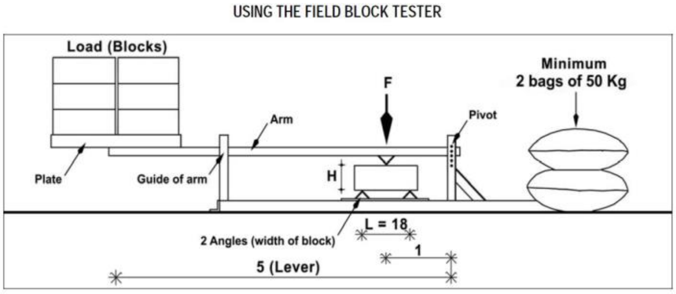

Figure 11: 3-point bending test from Auroville rapport

7.2.5 Lever arm test (adjustment to the 3-point bending test)

The load test can also be adjusted in a way to make the test quasi static with a lever arm. This method is started with a hypothesis about the compressive strength calculated from the compressive tester. The idea of this method developed when a 3 point bending test at the office of Build Up Nepal was found. First the test was used to test the bricks but the device turned out to be too small wherefore the bricks did not fail but the device itself. For this reason a design was for an adjusted version of the tester (see Figure 13 and Figure 14).

Figure 12: Lever arm device

In our design there is a local pressure exerted on the brick with a moment. After some calculations (see Table 1) the design was executed and as a result the device exert a local pressure on a small area in the middle of the brick. This force is large enough to break the brick.

Amount of bricks	**Mass (bricks) [kg]**	**Mass (lever arm) [kg]**	**Mass total [kg]**	**Force [N]**	**Pressure on brick**	**Pressure [Mpa]**
1	7,5	8,7	64,6	633,6	1013828,3	1,0
2	15,0	8,7	100,0	980,7	1569111,4	1,6
3	22,5	8,7	135,3	1327,7	2124394,4	2,1
4	30,0	8,7	170,7	1674,8	2679677,4	2,7
5	37,5	8,7	206,1	2021,9	3234960,4	3,2
6	45,0	8,7	241,5	2368,9	3790243,4	3,8
7	52,5	8,7	276,9	2716,0	4345526,4	4,3

Table 1: Calculations lever arm design

$$Contact\ area = 0{,}000625\ m^2$$

$$Total\ mass = \frac{1{,}25\ m\ x\ weight\ bricks +\ 0{,}895\ x\ weight\ leverarm}{0{,}265}$$

$$Pressure\ (MPa) = \frac{Total\ force}{Contact\ area}$$

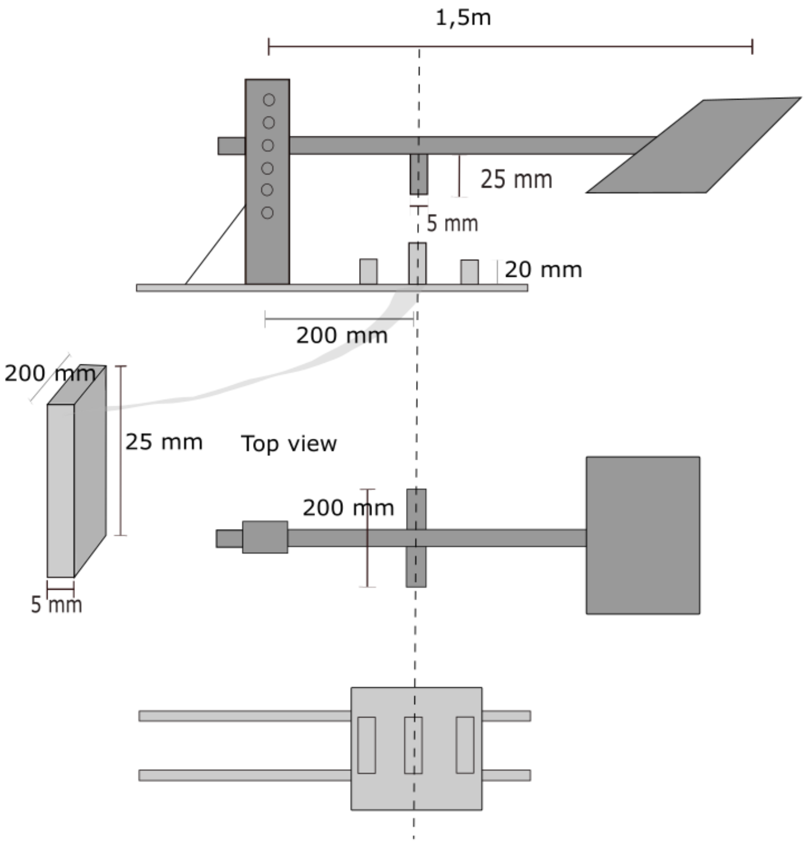

Figure 13: Design lever arm device

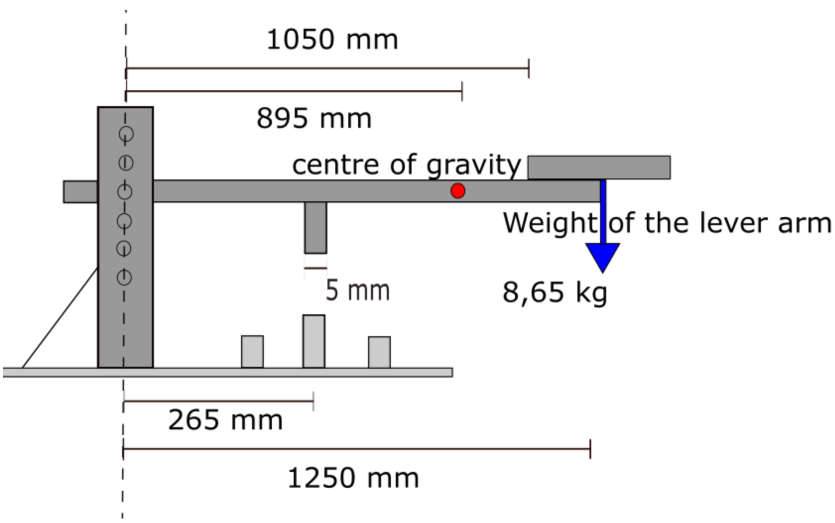

Figure 14: Distances used in calculations moment equilibrium

7.2.6 Torque wrench and vice

Around a month before heading to Nepal, Build up Nepal was working on their torque wrench and vice to test the compressive strength of CSEB. This looked like a good alternative for a compression tester. First, the torque wrench with the vice needed to be calibrated.

The torque wrench and vice were transported to our building site at Lubhu. First a fully cured CSEB was tested, but the CSEB did not break, instead the vice broke. This was a setback for us, since this was our alternative testing device. Together with Build Up Nepal, and us were in doubt, because this device has some potential to be used as a test device, although the materials should be of a better quality. However when higher quality materials are bought the test will be too expensive and will not meet the requirement anymore.

7.2.7 Compression test

The device used by Build Up Nepal to test the strength the bricks is a compression tester. This is a fairly large device which costs quite much for Nepali standards, around 2000 dollars. With an arm the pressure inside the device is built up, which is displayed on a screen. For CSEB however the range of the pressure was starting to late, which meant that it was difficult to see how the pressures developed in the lower range. In general, the freshly made CSEB compressive strength is lower than 1 MPA, while the compression test only started showing values from around 3 MPA.

7.2.8 Smaller compression test

This could be an option, and involves the little extra work. The device would just a resized compression test. The conventional compression test is not designed for CSEB but for concrete. Ideally for CSEB, a smaller range is needed. A small range of compression test could be the solution, but would still be quite expensive.

7.2.9 Hydraulic press

The compression test is a hydraulic test, but there are also other kinds of hydraulic test available. One of them is a hydraulic bearing press. These are available in different kinds of ranges such as 0-12 tons and 0-20 tons. These ranges might be quite interesting for designing compression tester for CSEB. The design is quite simple, which could be easily made by the engineers in Nepal. Ordering a hydraulic press and testing it was not possible in our time frame, but it can still be a interesting subject for further research.

8. Results

8.1 Compression test (setting up hardening curve)

The results of the compression test are somewhat different than expected. There is a big difference in the 0 - 21 days and the 0 - 38 days strength development. This is due to the fact that only until 21 days the bricks get cured twice a day. Only afterwards, the bricks really started drying. Our initial idea was to end the tests at 28 days, which is the time CSEB get tested according to the norms (and the same time as concrete). However, after testing and breaking the bricks of 28 days old, there was still moist inside the brick. This insinuated that the bricks were not nearly on full strength, which resulted in the choice of testing bricks after 38 days as well. The graph of the 0-38 days (Figure 9) shows this sudden strength gaining behaviour, but is not of any scientific significance. It only shows how fast the hardening process accelerated after the 21 days. To get the right hardening curves only the 0-21 days tests have been used, because these results are comparable. That is, the point of 21 days is a discontinuity in terms of factors (curing to no curing).

Figure 9 shows that after the 21 days, the CSEB only really starts developing some strength. After 28 days (when the bricks should be somewhere near full strength), the strength development really starts growing quickly. 38 day testing was the most, which could be done in the available time. According to the graphs, in general CSEB shows that the 38 days MPa's are double the 28 days MPa's, while in theory they should be somewhere in the same league.

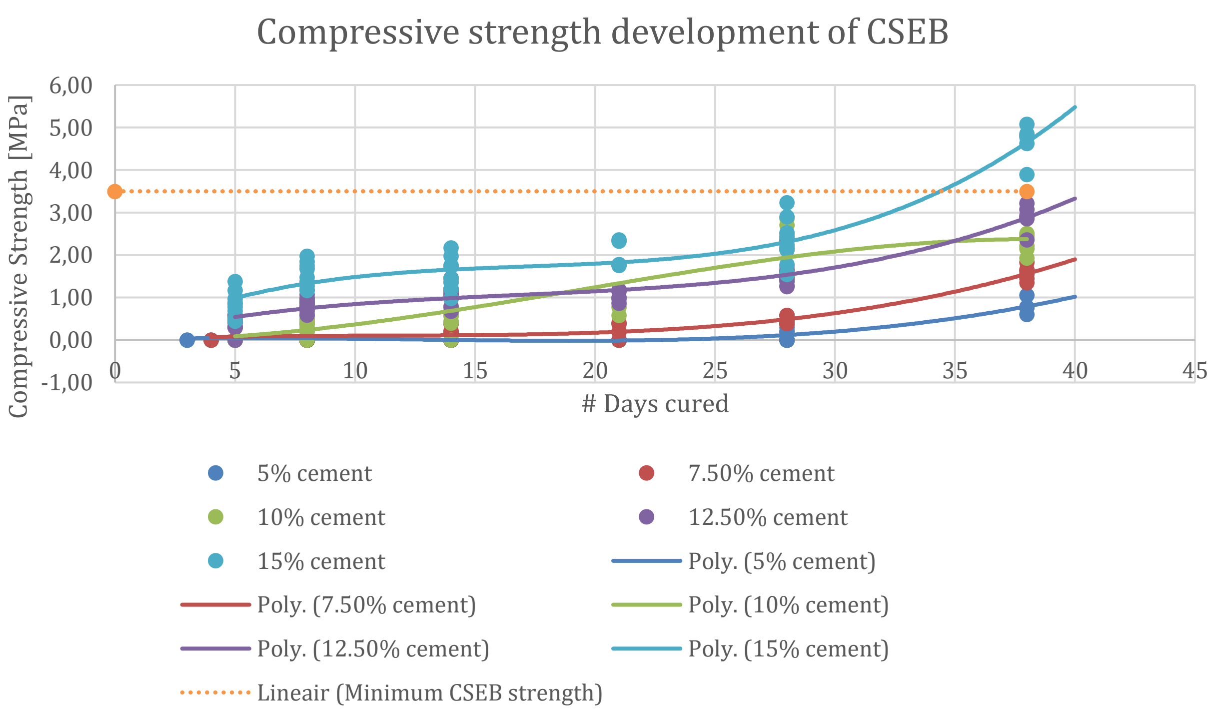

Figure 15: Compressive strength development of CSEB (0-38 days)

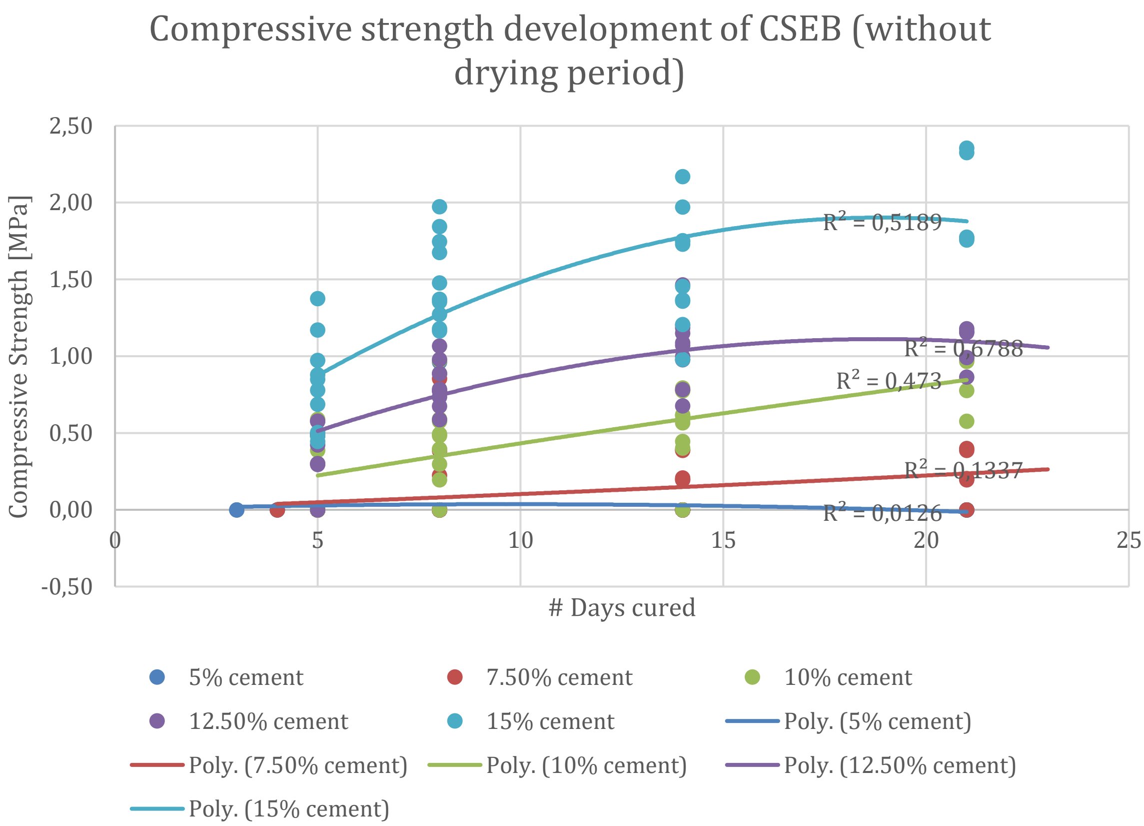

Figure 16: Compressive strength development of CSEB (0-21 days)

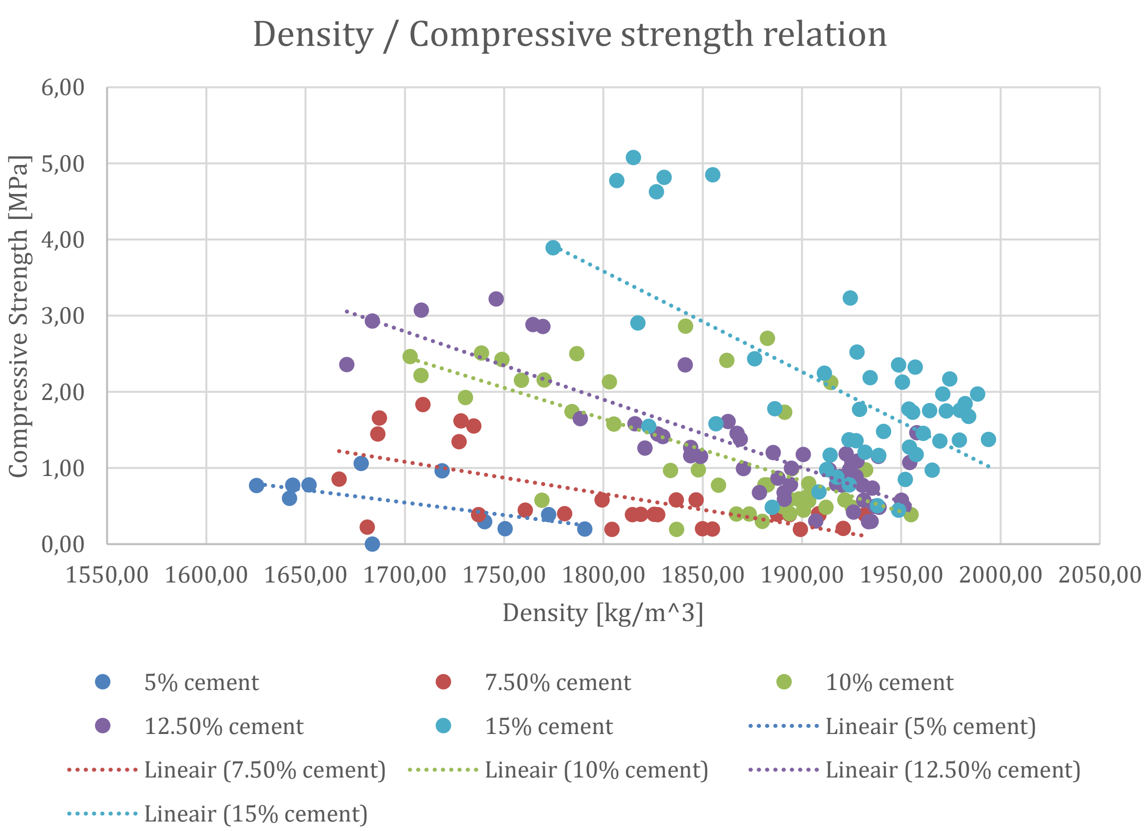

Figure 17: Density/ Compressive strength relation

The results for the lower percentages of cement (mainly 5% and 7.5%, which are basically mud) do not show a lot of strength development at all. Most differences in measured strength are (see Figure 10). coming from a different time period between the curing of the bricks and the testing of the bricks. The 10% cement bricks show some strength development, but it is hard to draw a curve out of it. The 12.5% and 15% cement bricks show a slight curve, which is better than nothing, but it is not great.

8.2 General CSEB strength

All above results are discussed in relative form, so the MPa's of different bricks are compared to each other and set out in a graph. This however, is maybe not the most interesting result of the compression tests. Looking at the results (even the 0 - 38 days tests) a conclusion can be drawn that the overall quality of the bricks is unquestionably low. Only the bricks with 15% of cement surpass the minimum strength of 3.50 MPa, set by the Nepali Government.
After noticing this behaviour (around December), several bricks for Build Up Nepal were tested from the same site but a different batch (not made by our team). These bricks also showed the same lack of compression strength, although this was not the case the last time these were tested (around June).

Furthermore, during the 28 and 38 day tests the level of moist in the brick is recorded (by eye) to check if this is relatable to the compressive strength of the brick. No clear correlation has been found, probably due to the inaccurate way of recording. However, moisture content is not only visible by eye, but can also be related to the density. The denser the brick, the higher the moisture content. The relation of the density / compressive strength is shown in the graph above. It is clear that the density of a brick is inversely proportional to the their compressive strength.

8.3 Alternative testing method

8.3.1 Lever arm test

The first step of designing this testing method was determining the required weight to break the brick. This was done based on the assumed minimum strength of the bricks. With some simple static calculations of the force equilibrium the weight on the system can be converted into a pressure in MPa to be able to compare the results of lever arm to the compression tester. This is done to examine if this test method is usable or not.

A batch of bricks (12,5% cement from which the strength was already know form previous compression test), was manufactured and used to validate this testing method.
As the amounts of ingredients and outdoor conditions always vary half of the batch was tested with the compression tester after six and eight days. The other half was used to test with the lever arm tester. In other words, the same batch of bricks was used for both test devices so that the testing methods could be compared. First the weight of bricks that lead to failure with the lever arm was determined and converted to a force on the brick. Then the strength of the brick in MPa was computed to compare because the area that is tested is different for both methods. The total weight on the lever arm tester is determined by the weight of the bricks that are placed on the lever arm and thus with the accuracy is +/- the weight of one brick. This accuracy is acceptable because of the way it will be implemented in practice.

The goal is that all bricks should be strong enough to survive the lever arm test with the weight of a certain amount of bricks after a certain amount of days.

Against expectations, the strength of the lever arm tested bricks was much higher than the strength of the bricks tested with the compression tester. This demonstrated that the results from the different cannot be directly compared to each other. First of all, this is because the brick might have a lot of small imperfections and small cracks. The chance of imperfections present in the cross-section tested by the lever arm is smaller and therefore the tested strength will be higher than the actual strength including imperfections. However if an imperfection would be present it would be expected that the brick would fail at a lower stress. Secondly, the lever arm test is not really a compression test but rather a splitting test. Instead of the compressive strength a tensile strength or a combination of both strength is actually being tested.

For concrete the splitting test is applied to determine the tensile strength. In practice, the tensile strength can be derived from the compressive strength. NEN 6720 provides formulas for this. In general, the tensile strength is about 10% of the compressive strength. (NEN 6720, 1995)
The determination of the splitting tensile strength is carried out in accordance with NEN-EN 12390-6. For concrete there is a factor to calculate the compression strength on account of the splitting tensile strength. With the obtained results it was possible to calculate this factor and determine whether a correlation exists between the results both testing methods (see table 2). The factor calculated for the batch that cured six days is 0,165 and the factor for the eight-days batch is 0,186.

Determination factors to convert	Lever arm test (MPa)	Compression test (MPa)	Factor
Average strength 6 days	3,42	0,57	0,165
Average strength 8 days	3,99	0,742	0,186

Table 2: Converting factors lever arm test

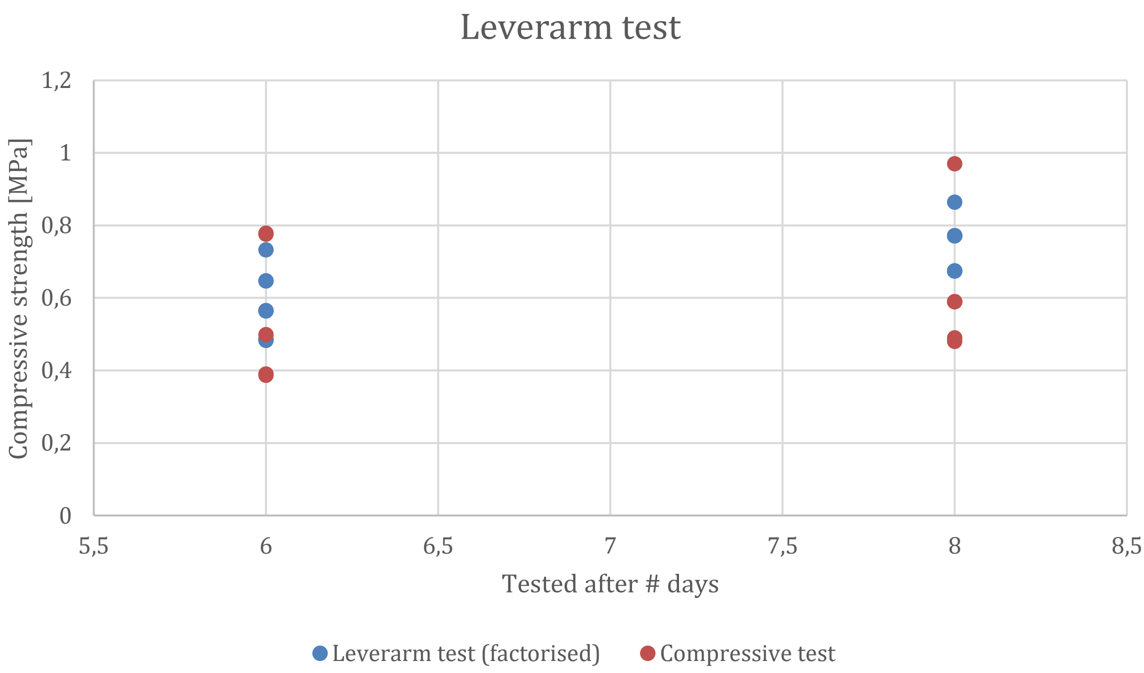

Figure 18: Comparison lever arm test and compressive test

In the graph above the difference between the factored lever arm test and the corresponding compressive test results are shown. Through the conversion factor the tested splitting strength is somewhat converted into a relatable compressive strength of the CSEB. These results are alike the results from the corresponding compressive tests. The graph shows there is a larger variation in the results of the compression tester and the results of the lever arm have a smaller deviation.

8.3.2 Drop test

The results of the drop test were so scattered, that there was no reason trying to find links between the several tests. However, the results of the tests are added in Appendix 12.5. Some bricks broke immediately after one drop from a low height, while other bricks of the same consistency only broke after repeating the test 6 times in a row, every time from an increasing height.

9. Conclusion and discussion

9.2 Compression test

It is concluded that the curing of the bricks greatly influences the strength of the CSEB, so it is hard to say something about the relation between the 5 and 28 days strength of the CSEB.

The curves from 0 - 21 days differs a lot from the curve from 21 - 38 days: While the lower cement percentages show no real gain in strength during the first 3 weeks, the higher cement percentages show a more and more distinctly rising strength value over time, and finally reaching a relatively constant value. This is similar to concrete hardening curves. This is due to the lower ones being basically mud, so the time period between curing the bricks and testing them massively influences the strength (of hardness so to say) of the bricks. The higher percentages show this behaviour to a lesser degree, because these bricks show behaviour that keeps the middle between mud-only bricks and concrete.

General conclusion is drawn that the time period between the curing and testing of the brick makes a significant difference in the results, so this has to be monitored accurately. During our testing period we tried to actively monitor the time the bricks were dried, but in practice this is really hard to control. Mostly due to both language and cultural differences.

9.2 General CSEB strength

There are multiple reasons applicable for the low overall strength of the bricks. Firstly, the time between the two testing moments where 6 months apart. In addition, the moments were in respectively summer and winter. It is very likely that moisture content in both seasons differs significantly, thus influencing strength.

Furthermore, the compound of the bricks can have changed during this time period. The mixture of the bricks consists of soil, sand, cement and some additions such as clay and silt. The sand and other additions are used to improve the sub-optimal source material that is used as basic ingredient. However, every time a new batch of soil comes in, this composition can vary. Therefore, a soil test needs to be performed every time a new soil batch arrives. This hasn't been done since last summer, so there is a big chance the brick compound in winter was not at the level it should be, explaining the low general strength.

9.3 Alternative testing method

9.3.1 Lever arm test

From the results of the lever arm test it became clear that this testing method can be used and implemented when certain requirements are met. The conversion factor should be known to translate the strength obtained by the lever arm to the actual compressive strength. Also, the material property that is actually being tested by the lever arm tester should be known.
The factor calculated in our research after six and eight days of hardening respectively is 0.16 and 0.20. There is a difference in the conversion factors because the hardening time and drying of CSEB has more influence on the strength determined by the compression test due to the imperfections always being present. The lever arm test already gives high values at earlier stages and the strength will not increase a lot

further. To know this for sure more research is necessary. The bricks were only tested at six and eight days of curing due to time constraints of the project. The factor will increase with increase of the days and therefore the method is only usable when the factors for different days are determined. This should be translated to a simple method, rule of thumb, that can be carried out in practice on the building site; for example that all the bricks should pass a quality control if they withstand a certain weight at a specified curing time.

As mentioned earlier, the tensile strength of concrete is about 10% of the compressive strength. For CSEB somehow the tests show contrary results, the tensile splitting strength is about six times higher than the measured compressive strength.
It is not clear to what extent the executed tests work as a tensile splitting test. Furthermore, some measurements were not exact, for example the brick surface that is pressured with the device, because of limited measuring tools in Nepal and thus the calculations could differ from reality. Finally, the imperfections might have a bigger influence on the total strength than expected. Another explanation could be that, because the compression test device was transported several times and has to be calibrated every time, it was not properly calibrated when it was used in Lubhu. This would also be a reason for the low compressive strength of the bricks after drying (<3,5MPa).

9.3.2 Drop test

The drop test was executed at the request of Build Up Nepal. The advice is to not use the drop test as a testing method for early strength testing, as the results are not reliable. As the tests showed, there is no direct correlation visible between drop height and strength.

9.4 Earthquake Engineering

Earthquake engineering in Nepal is actually quite developed. At the visit to NSET we saw detailed Finite Element Models of brick and even rubble stone houses. They currently work on proving the effect of horizontal bands, a request also opted by local parties as we learned in a visit to Architecture Sans Frontieres. The difference between Nepal and Western countries is that publication of these research results does not actually help much. Few engineers and architects can work with them and even if they can they cannot explain the importance of certain design choices. Scientific publications will almost never be followed by the craftsman or ordinary people building the, or even their own, houses. Instead of a scientific publication they establish a design catalogue (Government of Nepal, 2017). If houses are build according to the guidelines of the catalogue the owners obtain funding from the government. As many Nepali do not have much money they all try to do their best to follow these guidelines.

If the guidelines are followed well the buildings have some earthquake capacity. They do not ensure safety in the event of a large earthquake but ensure some safety and can certainly decrease the potential damage. The guidelines ensure that the rooms and spaces are quite rigid; avoid slenderness and work with cubic frames in story-buildings. They ensure that the influence of the quality of the foundation is not underestimated, it is the first step to be approved to receive funding. The roof should be lightweight. Horizontal bands should be applied. All these factors contribute to a design in which the integrity and ductility of the building should not produce large deformations in the event of an earthquake. Furthermore, the quality control to obtain the governmental funding is a very good insurance that execution will be done well (enough).

10. Recommendations

10.1 Strength development

Further research of the influence of the amount of curing (and the effect of it in different seasons) is necessary to be able to use the hardening curves. During the research, a big variation in measured strength due to the time of curing was seen. It is extremely difficult to set at what time a day the bricks are getting cured and what influence on the moisture content this curing exactly has. However, it is important that the time between curing and testing is constant, in order to get usable results.

The compression testing machine itself is a good device to get usable results for setting up the hardening curves. However, this machine must be calibrated every time it has been moved. In our time in Nepal the device has been moved without being calibrated afterwards, which amplifies the chance that the results are not accurate.

10.2 Alternative testing method

Further research is required on the strength development of the CSEB throughout time tested by the lever arm. Such information would facilitate the implementation of the lever arm method.

First, it is necessary to know to what extent the lever arm test works as a tensile splitting test. This could be investigated, for instance testing, by concrete with both the lever arm test and the compression test. From the codes it is known that the concrete tensile splitting strength is about 10% of the compression strength. If the lever arm test results would indicate a concrete strength of 10% of the strength obtained with the compression tester, then it could be concluded that the lever arm works as a tensile splitting test. In that case the lever arm would not be usable to indicate final pressure strength directly. When the strengths resulting by the lever arm test turn out to be higher than tested with the compression tester it might be possible to relate both devices and use the calculated factors to determine the compressive strength of CSEB. The remaining question in this case is what property is tested with the lever arm? The tested property could be a combination of compressive strength and tensile strength. Further research about this is recommended.

10.3 Earthquake Engineering

The validation of the pilot house was done on a simple quasi-dynamic level by team 5 and can be done in a more detailed way. FEM can be applied, the foundation can be modelled, site investigations are a possibility. But this will not be the best way to help the Nepali. The local parties as NSET and SSF have a better idea of what is currently a technical issue in Nepal and they are more in the execution than in the seismic design area. If a future team decides to do a technical project and want to do (theoretical) research they are recommended to contact such parties to come to a relevant subject.

Currently the biggest problem, as learned at the monthly HRRP meeting in December 2017, is that information is hard to spread in Nepal. Internet is only accessible to a small part of the population and the content is not deemed reliable. Their most reliable resource is actually the word of their friends and family. So even organizations trying to be a an open source as the Smart Shelter Foundation do not have an audience as big as they'd like to have. Being in Nepal and actually talking to the people in real life and to convince the right people of what is important in earthquake resistant housing is crucial. This makes the mission of Shock Safe Nepal extremely hard, only being present in the country with a small group of students who have to adapt to the country for a large part of their time there.

Social aspects thus a promising field for Shock Safe Nepal to continue the project. The current problems in rebuilding and improving quality in earthquake resistant housing are social problems. Problems in information distribution, problems in collaboration between NGO's, government and research institutions, problems that come with remote areas, problems in sustainability. Shock Safe Nepal has made contacts and a good outline of problems the rebuilding is dealing with. Though stressed that local organizations and parties are always more knowing and helpful to establish the right direction.

We can close the chapter of the pilot house as it is initial idea is to be an example and to learn from the difficulties that come with the execution of the house. It has been analysed statically and dynamically. It has been deemed safe theoretically though not in reality as knowledge and time are short in Shock Safe Nepal teams. Further research will not be actually helpful to the mission of SSN.

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List of figures and tables

12. Appendices

12.1 Production of CSEB

1. Sieving

First the soil and sand is sieved to separate the smaller grains from the bigger ones. The sieve used for soil is more fine than the one used for sand. In image 17 the soil is sieved and in image 18 the sand is being sieved.

Figure 19: Sieving of soil

Figure 20: Sieving of sand

2. Jar Test

To know the composition of the soil, a jar test was performed. As seen in image # the sand consist of around 5% of gravel. This assumption is made by our visual observation. The soil consist of clay, silt and a small percentage of sand after sieving. The ratio is respectively 45:50:5, tested by a jar test. The jar test is executed by filling a jar with soil up to a height of 5 cm. Then the remaining part of the jar is filled with water. Then the jar is closed and shaken until all of the soil is mixed with the water. After several hours the picture was made, and the composition was established. To get to the ideal soil mixture, additional sand is added.

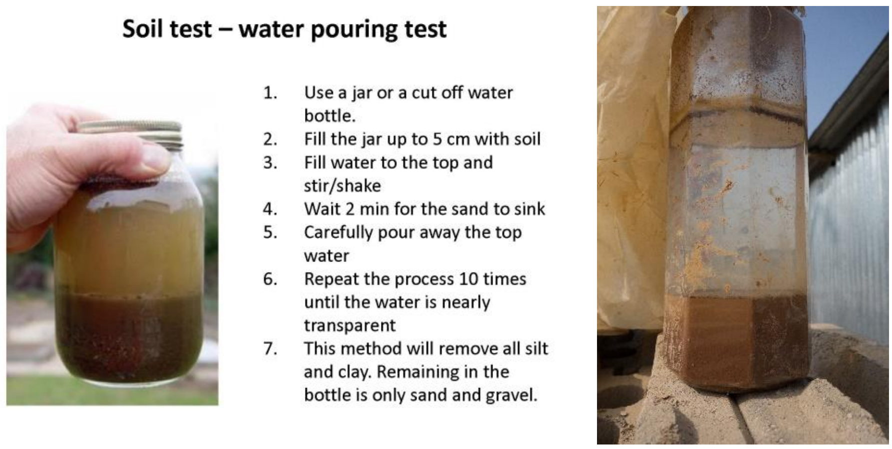

Figure 21: Jar test

Materials	Jar Test Results (Soil)	Jar Test Results (Sand)
Sand	0.05	0.95
Clay	0.4	0
Gravel	0	0.05
Silt	0.55	0
TOTAL	1	1

Table 3: Results Jar Tests

Ideal soil mix composition	Material Needed for ideal soil mix [L]	Soil [L]	Sand [L]	Test composition [L]	Test composition
0.5	1050	45	1140	1185	0.56
0.2	420	360	0	360	0.17
0.15	315	0	60	60	0.03
0.15	315	495	0	495	0.24
1	2100	900	1200	2100	1

Figure 22: Additional material added

3. Mixing of ingredients

As a result the dry mix of soil and sand consist of 56% sand, 19% clay, 3% gravel and 21% silt. In total a volume of 2100 litres of soil mix is made.

First the sand and soil is collected and put on a large sheet. By putting all the material on the sheet all the bricks will consist out of the same soil mix. The soil and sand might be a little wetter in the morning and slightly dryer in the afternoon. In the evening the soil mix is covered with a plastic sheet to minimize evaporation.

Figure 23: Mixing of ingredients

Materials	Composition [L]	Composition [%]
Sand	1185	0.56
Clay	360	0.17
Gravel	60	0.03
Silt	495	0.24
TOTAL	2100	1.00

Figure 24: Composition used in Lubhu for CSEB

4. Adding Cement

Before adding the cement, the correct amount of the mixture is put under the shelter. The cement is added and mixed until all the ingredients are mixed well. The sand/soil ratio that is used for making the CSEB is 3:4. This is the ratio used determined by experience with the local soil. In our research the ratio has to be as much as the ratio used normally in order to relate it to reality.

	Composition 1	Composition 2	Composition 3	Composition 4	Composition 5
Cement[%]	5	7.5	10	12.5	15
Soilmix[%]	95	92.5	90	87.5	85
Cement [L]	22.43	33.64	44.85	56.06	67.28
Soilmix [L]	426.09	414.88	403.67	392.45	381.24

Table 4: Cement ratios different compositions

5. Adding Water

After mixing, the water is added. The amount of water is between the minimum and maximum according to the water/cement ratio. We gave the construction workers, who pressed the bricks and mixed the cement and water, the freedom to choose the amount of water between this range to keep the quality of the bricks as high as possible. We monitored the amount of water by filling a bucket with 10 litre of water and then filling a watering can with this 10 litre. The ratio between water and cement in case of CSEB is less important than this ratio when producing concrete. This because the bricks are after pressing cured by water twice a day. Concrete is only a matter of hardening but with CSEB it is a combination of drying and hardening.

	Composition 1	Composition 2	Composition 3	Composition 4	Composition 5
Cement[%]	5.00	7.50	10.00	12.50	15.00
Soil mix[%]	95.00	92.50	90.00	87.50	85.00
Cement [L]	22.43	33.64	44.85	56.06	67.28
Soil mix [L]	426.09	414.88	403.67	392.45	381.24
w/c factor min	0.35	0.35	0.35	0.35	0.35
w/c factor max	0.50	0.50	0.50	0.50	0.50
mass cement [kg]	32.04	48.06	64.07	80.09	96.11
mass water min [kg]	11.22	16.82	22.43	28.03	33.64
mass water max [kg]	16.02	24.03	32.04	40.04	48.06
Water Used [L]	16.50	21.00	25.00	30.00	35.00

Table 5: Different compositions made

Figure 25: Adding of water

6. Turning mixture into bricks

After mixing the sand, soil, cement and water the mixture is put in the CSEB machine. The machine compresses the mixture and turns it into a CSEB.

On the first day of production we made, together with two Nepali workers the bricks that contain 5% and 7,5% cement. The aim was to make at least 72 bricks of each composition to be able to test 9 bricks at one time step of each composition. In the end we made 76 bricks with 5% cement and 79 bricks with 7,5% cement. The day after we made the remaining compositions with 10%, 12,5% and 15% cement. Everything was done following the same method as with the other bricks. 80 bricks of 10% were made, 79 bricks of 12,5% and 78 bricks of 15% cement.

Figure 26: Turning the mixture into bricks

During the production of the first 3 CSEB compositions, water was added during the production. The bricks started showing cracks, when they were taken out of the pressing machine. This is probably caused by evaporation and the cement which has reacted with the water. That's why water was added to stop the bricks from cracking. This is shown in table 6.

	Composition 1	Composition 2	Composition 3	Composition 4	Composition 5
Cement[%]	5.00	7.50	10.00	12.50	15.00

Soilmix[%]	95.00	92.50	90.00	87.50	85.00
Water Used [L]	16.50	21.00	25.00	30.00	35.00
Water added after 35 bricks [L]	**1.00**	**0.50**	**0.50**	0.00	0.00
After 55 bricks [L]	0.00	**0.50**	0.00	0.00	0.00

Table 6: Extra water added

7. Cut off the protruding parts

After pressing the bricks with the CSEB machine, we had to cut off the protruding parts at the top of the brick. The reason for this is to be able to create a uniform pressure on the brick during testing.

Figure 27: Cutting off the protruding parts

8. 24 hours hardening

The first 24 hours the bricks are stored in the shelter, on iron bars. The bricks need to harden in order to be stored in stacks, otherwise they would break.

Figure 28: Hardening of CSEB

9. Stacking and curing

After 24 hours the bricks are strong enough to be stored. First a layer of gravel is put on the ground so that the bricks which lay at the bottom won't lay in the mud when water is applied to the bricks. When the small stones are levelled the CSEB is layered. When all the CSEB is stacked the bricks are covered with a plastic sheet and on top a sheet of burlap.

Every 12 hours the stones are being wetted, this is done because otherwise the bricks might crack during hardening. During 21 days the bricks are cured and after the bricks are drying/hardening another 7 days. In total the production takes 28 days, and after this time the bricks reach their final strength.

12.3 Compression test results

Tested after #days	Cement %	Brick No	Weight (kg)	Count 1st crack (-)	Load 1st crack (kN)	Count Failure (-)	Failure Load(KN)	Mpa	Density(kg/m^3)
0	5	0	7.000	0	0.0	0	0	0.00	1805.92
3	5	1	7.000	0	0.0	0	0	0.00	1805.92
3	5	2	7.147	0	0.0	0	0	0.00	1843.84
4	5	1	7.306	10	0.0	10	0	0.00	1887.90
4	5	2	7.318	20	0.0	20	0	0.00	1892.53
5	5	1	7.245	29	0.0	29	0	0.00	1869.79
5	5	2	7.274	28	0.0	28	0	0.00	1878.17
5	5	3	7.215	21	0.0	21	0	0.00	1861.76
5	5	4	7.239	20	0.0	20	0	0.00	1868.14
5	5	5	7.052	29	0.0	29	0	0.00	1839.48
5	5	6	7.537	41	0.0	41	0	0.00	1944.45
5	5	7	7.209	31	0.0	31	0	0.00	1861.02
5	5	8	7.341	29	0.0	29	0	0.00	1894.75
5	5	9	7.071	30	0.0	30	0	0.00	1824.40
5	5	10	7.263	27	0.0	27	0	0.00	1874.05
8	5	1	7.350	27	0.0	27	0.000	0.00	1896.98
8	5	2	7.201	27	0.0	27	0.000	0.00	1858.71
8	5	3	7.345	24	0.0	24	0.000	0.00	1895.50
8	5	4	7.175	24	0.0	24	0.000	0.00	1855.27
8	5	5	7.232	25	0.0	25	0.000	0.00	1866.82
8	5	6	7.148	26	0.0	26	0.000	0.00	1845.22
8	5	7	7.317	24	0.0	24	0.000	0.00	1888.08
8	5	8	7.174	21	0.0	21	0.000	0.00	1850.95
8	5	9	7.343	20	0.0	20	0.000	0.00	1894.41
8	5	10	7.316	21	0.0	21	0.000	0.00	1895.27
8	5	11	6.484	13	0.0	13	0.000	0.00	1683.59
8	5	12	6.662	30	15.0	44	25	0.96	1718.80
14	5	1	7.131	13	0.0	13	0	0.00	1839.71
14	5	2	7.234	22	0.0	22	0	0.00	1867.23
14	5	3	6.877	17	0.0	17	0	0.00	1774.36
14	5	4	7.098	18	0.0	18	0	0.00	1833.61
14	5	5	7.232	24	0.0	24	0	0.00	1866.90
14	5	6	7.167	19	0.0	19	0	0.00	1849.56
14	5	7	7.186	13	0.0	13	0	0.00	1854.65
14	5	8	7.390	9	0.0	9	0	0.00	1908.10
14	5	9	7.247	17	0.0	17	0	0.00	1869.83
14	5	10	7.292	10	0.0	10	0	0.00	1881.92
21	5	1	6.974	29	0.0	29	0	0.00	1800.12
21	5	2	7.169	26	0.0	26	0	0.00	1850.27

21	5	3	6.740	25	0.0	25	0	0.00	1739.01
21	5	4	6.981	28	0.0	28	0	0.00	1801.20
21	5	5	7.107	14	0.0	14	0	0.00	1835.50
28	5	1	6.749	41	0.0	41	0.000	0.00	1748.89
28	5	2	6.756	42	0.0	42	0.000	0.00	1745.09
28	5	3	6.775	37	5.0	37	5.000	0.20	1750.45
28	5	4	6.935	46	5.0	46	5.000	0.20	1790.61
28	5	5	6.740	32	5.0	37	7.500	0.30	1740.22
28	5	6	6.831	31	0.0	31	0.000	0.00	1767.96
28	5	7	6.869	34	10.0	34	10.000	0.39	1772.34
28	5	8	6.986	37	0.0	37	0.000	0.00	1803.46
28	5	9	6.741	32	0.0	32	0.000	0.00	1745.61
28	5	10	6.986	40	0.0	40	0.000	0.00	1805.06
38	5	1	6.356	54	5.0	60	15	0.60	1641.89
38	5	2	6.369	57	20.0	57	20	0.77	1643.46
38	5	3	6.400	58	15.0	64	20	0.78	1651.79
38	5	4	6.300	47	15.0	51	20	0.77	1625.32
38	5	5	6.504	46	22.5	51	27.5	1.06	1677.95
0	7.5	0	7.000	0	0.0	0	0	0.00	1805.92
4	7.5	1	7.330	13	0.0	13	0	0.00	1892.58
5	7.5	1	7.479	30	0.0	30	0	0.00	1930.84
5	7.5	2	7.192	29	0.0	29	0	0.00	1857.71
5	7.5	3	7.110	32	0.0	32	0	0.00	1834.57
5	7.5	4	7.139	34	0.0	34	0	0.00	1850.13
5	7.5	5	7.432	34	0.0	34	0	0.00	1917.66
5	7.5	6	7.294	33	0.0	33	0	0.00	1881.95
5	7.5	7	7.215	41	0.0	41	0	0.00	1861.67
5	7.5	8	7.286	41	0.0	41	0	0.00	1886.56
5	7.5	9	7.274	43	0.0	43	0	0.00	1876.98
5	7.5	10	7.386	34	0.0	34	0	0.00	1907.17
8	7.5	1	7.248	21	0.0	21	0	0.00	1876.52
8	7.5	2	7.220	26	0.0	26	0	0.00	1862.86
8	7.5	3	7.298	27	0.0	27	0	0.00	1886.62
8	7.5	4	7.206	25	0.0	25	0	0.00	1860.19
8	7.5	5	7.398	29	10.0	29	10	0.38	1908.59
8	7.5	6	7.274	27	0.0	27	0	0.00	1876.79
8	7.5	7	7.214	30	0.0	30	0	0.00	1861.60
8	7.5	8	7.303	29	0.0	29	0	0.00	1884.28
8	7.5	9	7.035	28	0.0	28	0	0.00	1815.31
8	7.5	10	7.332	31	0.0	31	0	0.00	1894.81
8	7.5	11	6.486	25	5.0	25	5	0.22	1681.12
8	7.5	12	6.459	37	20.0	40	22	0.85	1666.85
14	7.5	1	7.147	20	0.0	20	0	0.00	1845.52
14	7.5	2	7.269	16	0.0	16	0	0.00	1876.65
14	7.5	3	7.358	19	0.0	19	0	0.00	1904.56
14	7.5	4	7.428	14	0.0	25	5	0.21	1920.85

14	7.5	5	7.486	13	0.0	24	10	0.39	1931.69
14	7.5	6	7.249	13	0.0	13	0	0.00	1872.62
14	7.5	7	7.184	21	0.0	22	5	0.20	1854.89
14	7.5	8	7.358	21	0.0	22	5	0.20	1899.24
14	7.5	9	7.192	20	0.0	20	0	0.00	1859.06
14	7.5	10	7.313	17	2.5	26	10	0.39	1887.62
21	7.5	1	6.990	18	0.0	31	5	0.20	1804.27
21	7.5	2	7.388	23	0.0	34	10	0.40	1908.37
21	7.5	3	7.157	24	0.0	31	5	0.20	1849.85
21	7.5	4	7.227	28	0.0	0	0	0.00	1870.96
21	7.5	5	7.339	18	0.0	32	10	0.39	1893.76
28	7.5	1	6.732	35	10.0	35	10	0.39	1737.17
28	7.5	2	6.794	32	10.0	32	10	0.44	1760.58
28	7.5	3	7.080	32	10.0	32	10	0.39	1827.26
28	7.5	4	6.892	38		42	10	0.40	1780.42
28	7.5	5	6.973	34	12.5	38	15	0.58	1799.31
28	7.5	6	7.118	33	10.0	40	15	0.58	1836.64
28	7.5	7	7.046	33	5.0	38	10	0.39	1818.81
28	7.5	8	7.157	27	12.5	33	15	0.58	1846.61
28	7.5	9	7.073	28	10.0	28	10	0.39	1825.59
28	7.5	10	7.031	30	5.0	35	10	0.39	1814.56
38	7.5	1	6.695	51	30.0	56	35	1.35	1727.23
38	7.5	2	6.688	47	32.5	51	40	1.62	1728.22
38	7.5	3	6.537	55	40.0	60	42.5	1.65	1687.15
38	7.5	4	6.722	67	37.5	70	40	1.55	1734.72
38	7.5	5	6.624	64	42.5	71	47.5	1.83	1709.09
38	7.5	6	6.536	45	37.5	45	37.5	1.45	1686.38
0	10	0	7.000	0	0.0	0	0	0.00	1805.92
5	10	1	7.336	28	15.0	28	15.000	0.59	1893.83
5	10	2	7.365	33	0.0	33	0.000	0.00	1901.44
5	10	3	7.461	32	12.5	32	12.500	0.48	1925.24
5	10	4	7.229	22	0.0	22	0.000	0.00	1867.31
5	10	5	7.306	24	0.0	24	0.000	0.00	1889.74
5	10	6	7.246	28	0.0	28	0.000	0.00	1885.67
5	10	7	7.204	24	0.0	24	0.000	0.00	1862.49
5	10	8	7.401	22	0.0	22	0.000	0.00	1933.23
5	10	9	7.576	27	10.0	27	10.000	0.39	1954.86
5	10	10	7.397	24	0.0	24	0.000	0.00	1908.53
8	10	1	7.294	26	0.0	26	0	0.00	1882.86
8	10	2	7.361	16	0.0	28	15	0.58	1899.05
8	10	3	7.230	26	10.0	26	10	0.40	1867.00
8	10	4	7.255	20	5.0	25	10	0.40	1873.45
8	10	5	7.321	21	10.0	22	12.5	0.49	1890.37
8	10	6	7.353	23	15.0	23	15	0.59	1898.52
8	10	7	7.410	6	7.5	21	12.5	0.48	1912.08
8	10	8	7.486	24	12.5	26	25	0.97	1932.08

8	10	9	7.280	11	0.0	25	7.5	0.30	1880.06
8	10	10	7.117	15	0.0	19	5	0.19	1836.84
14	10	1	7.370	31	15.0	35	20	0.79	1903.32
14	10	2	7.334	25	10.0	25	10	0.45	1900.73
14	10	3	7.359	23	5.0	30	15	0.62	1902.79
14	10	4	7.200	28	15.0	31	20	0.77	1857.89
14	10	5	7.300	23	5.0	29	10	0.57	1903.37
14	10	6	7.289	35	20.0	35	20	0.78	1881.24
14	10	7	7.331	23	5.0	28	10	0.40	1893.82
14	10	8	7.043	26	0.0	26	0	0.00	1822.74
14	10	9	7.446	23	10.0	26	15	0.58	1921.56
14	10	10	7.358	28	15.0	28	15	0.61	1902.13
21	10	1	7.083	30	20.0	26	22.5	0.97	1833.71
21	10	2	7.338	36	20.0	38	25	0.99	1894.84
21	10	3	7.295	37	20.0	37	20	0.78	1882.59
21	10	4	7.159	40	25.0	40	25	0.98	1847.79
21	10	5	6.857	28	0.0	45	15	0.58	1769.02
28	10	1	6.857	35	50.0	38	55	2.16	1770.12
28	10	2	7.420	37	50.0	41	55	2.12	1914.46
28	10	3	7.131	34	70.0	39	72.5	2.86	1841.27
28	10	4	7.217	35	60.0	41	62.5	2.41	1862.09
28	10	5	6.889	29	25.0	39	40	1.74	1784.08
28	10	6	6.925	32	42.5	49	65	2.50	1786.57
28	10	7	6.992	38	35.0	43	40	1.58	1805.29
28	10	8	7.331	36	35.0	44	45	1.73	1891.31
28	10	9	6.987	37	47.5	48	55	2.13	1803.03
28	10	10	7.296	34	55.0	51	70	2.70	1882.52
38	10	1	6.768	60	57.5	63	60	2.43	1748.90
38	10	2	6.611	54	55.0	54	55	2.22	1708.11
38	10	3	6.738	46	65.0	46	65	2.51	1738.59
38	10	4	6.793	46	50.0	46	50	2.15	1758.64
38	10	5	6.685	42	40.0	46	45	1.93	1730.45
38	10	6	6.518	45	40.0	45	40	2.46	1702.59
0	12.5	0	7.000	0	0.0	0	0	0.00	1805.92
5	12.5	1	7.333	17	0.0	17	0.000	0.00	1895.64
5	12.5	2	7.485	23	10.0	30	15	0.58	1931.14
5	12.5	3	7.514	26	12.5	30	12.5	0.48	1938.82
5	12.5	4	7.443	25	7.5	27	10	0.42	1925.92
5	12.5	5	7.559	24	12.5	27	15	0.58	1950.13
5	12.5	6	7.488	27	5.0	31	7.5	0.30	1933.50
5	12.5	7	7.491	9	0.0	24	7.5	0.30	1934.77
5	12.5	8	7.381	21	7.5	24	7.5	0.30	1906.93
5	12.5	9	7.558	17	0.0	27	12.5	0.49	1951.36
5	12.5	10	7.498	33	12.5	33	12.5	0.50	1936.66
8	12.5	1	7.442	19	5.0	27	20	0.77	1920.34
8	12.5	2	7.326	7	0.0	24	15	0.59	1891.17

8	12.5	3	7.481	12	0.0	33	17.5	0.74	1935.47
8	12.5	4	7.329	12	0.0	25	17.5	0.68	1890.99
8	12.5	5	7.427	13	0.0	26	20	0.79	1917.44
8	12.5	6	7.460	23	17.5	29	27.5	1.07	1925.18
8	12.5	7	7.464	21	20.0	25	22.5	0.89	1927.18
8	12.5	8	7.481	9	0.0	31	20	0.77	1930.40
8	12.5	9	7.433	17	10.0	26	22.5	0.89	1919.20
8	12.5	10	7.453	23	22.5	26	25	0.98	1923.95
14	12.5	1	7.498	28	22.5	31	28	1.15	1938.50
14	12.5	2	7.335	16	0.0	28	25	1.00	1894.64
14	12.5	3	7.299	28	30.0	28	30	1.20	1885.53
14	12.5	4	7.444	26	30.0	26	30	1.19	1922.21
14	12.5	5	7.572	8	0.0	27	27.5	1.07	1954.28
14	12.5	6	7.465	26	25.0	28	27.5	1.09	1927.66
14	12.5	7	7.280	26	15.0	28	17.5	0.68	1878.53
14	12.5	8	7.338	23	15.0	29	20	0.78	1894.18
14	12.5	9	7.414	27	20.0	30	25	0.98	1913.69
14	12.5	10	7.585	26	22.5	36	37.5	1.46	1957.83
21	12.5	1	7.362	28	20.0	38	30	1.18	1900.65
21	12.5	2	7.291	27	10.0	35	20	0.86	1887.87
21	12.5	3	7.167	33	25.0	38	30	1.15	1849.00
21	12.5	4	7.146	38	25.0	48	30	1.16	1843.96
21	12.5	5	7.243	33	10.0	44	25	0.99	1870.50
28	12.5	1	7.238	35	35.0	35	35	1.38	1868.87
28	12.5	2	7.033	42	35.0	47	40	1.58	1815.96
28	12.5	3	7.082	39	35.0	43	37.5	1.45	1827.26
28	12.5	4	7.210	35	35.0	41	40	1.61	1862.83
28	12.5	5	7.132	48	55.0	54	60	2.35	1841.16
28	12.5	6	6.930	37	35.0	44	42.5	1.65	1788.36
28	12.5	7	7.126	31	27.5	38	30	1.27	1843.98
28	12.5	8	7.236	31	35.0	35	37.5	1.45	1867.28
28	12.5	9	7.082	34	32.5	38	35	1.41	1829.84
28	12.5	10	7.056	33	25.0	39	32.5	1.26	1820.87
38	12.5	1	6.853	52	70.0	53	72.5	2.86	1769.43
38	12.5	2	6.832	59	72.5	59	72.5	2.89	1764.53
38	12.5	3	6.751	56	77.5	56	77.5	3.22	1745.92
38	12.5	4	6.608	43	65.0	49	75	3.07	1708.25
38	12.5	5	6.463	50	57.5	50	57.5	2.36	1670.75
38	12.5	6	6.523	65	72.5	68	75	2.93	1683.71
0	15	0	7.000	0	0.0	0	0	0.00	1805.92
5	15	1	7.616	21	15.0	26	25	0.97	1965.58
5	15	2	7.305	23	10.0	26	12.5	0.48	1884.94
5	15	3	7.416	23	25.0	28	30	1.17	1914.16
5	15	4	7.501	20	15.0	25	12.5	0.50	1938.02
5	15	5	7.454	24	17.5	26	20	0.78	1923.77
5	15	6	7.393	21	15.0	23	17.5	0.69	1908.61

5	15	7	7.543	21	12.5	26	20	0.85	1952.10
5	15	8	7.429	24	20.0	27	22.5	0.88	1917.57
5	15	9	7.723	21	20.0	28	35	1.38	1993.85
5	15	10	7.519	19	7.5	24	10	0.45	1948.64
8	15	1	7.518	24	25.0	33	37.5	1.48	1941.13
8	15	2	7.684	23	37.5	27	42.5	1.68	1983.99
8	15	3	7.681	19	22.5	27	47.5	1.84	1982.21
8	15	4	7.452	25	30.0	32	35	1.37	1923.70
8	15	5	7.582	23	25.0	27	30	1.18	1957.45
8	15	6	7.632	25	30.0	30	35	1.35	1969.36
8	15	7	7.570	15	0.0	28	32.5	1.27	1954.16
8	15	8	7.678	27	45.0	27	45	1.75	1981.43
8	15	9	7.512	26	20.0	40	30	1.16	1938.59
8	15	10	7.706	14	22.5	31	51	1.97	1988.46
14	15	1	7.647	27	50.0	31	55	2.17	1974.45
14	15	2	7.668	21	20.0	27	35	1.37	1979.25
14	15	3	7.477	9	0.0	26	30	1.21	1931.75
14	15	4	7.633	27	45.0	30	50	1.97	1970.82
14	15	5	7.599	20	25.0	27	37.5	1.46	1961.05
14	15	6	7.644	27	31.0	31	45	1.75	1972.66
14	15	7	7.611	15	10.0	27	45	1.75	1964.34
14	15	8	7.408	21	25.0	21	25	0.98	1912.34
14	15	9	7.468	23	30.0	26	35	1.36	1927.24
14	15	10	7.581	24	45.0	24	45	1.73	1955.81
21	15	1	7.669	36	35.0	45	45	1.76	1979.51
21	15	2	7.567	48	35.0	55	45	1.77	1953.80
21	15	3	7.548	42	55.0	51	60	2.35	1948.59
21	15	4	7.584	63	55.0	66	60	2.33	1957.09
21	15	5	7.472	37	35.0	47	45	1.77	1929.05
28	15	1	7.394	35	50.0	38	55	2.25	1911.24
28	15	2	7.559	37	50.0	41	55	2.13	1950.53
28	15	3	7.035	34	70.0	39	72.5	2.90	1817.34
28	15	4	7.269	35	60.0	41	62.5	2.43	1876.07
28	15	5	7.064	29	25.0	39	40	1.55	1822.75
28	15	6	7.470	32	42.5	49	65	2.52	1927.76
28	15	7	7.190	38	35.0	43	40	1.58	1856.58
28	15	8	7.305	36	35.0	44	45	1.78	1886.23
28	15	9	7.490	37	47.5	48	55	2.18	1934.34
28	15	10	7.418	34	55.0	51	70	3.23	1924.34
38	15	1	6.876	46	95.0	48	100	3.89	1774.64
38	15	2	7.067	45	110.0	45	110	4.82	1830.54
38	15	3	7.188	53	125.0	53	125	4.85	1854.98
38	15	4	7.032	55	125.0	59	130	5.08	1815.09
38	15	5	6.986	40	110.0	46	115	4.78	1806.70
38	15	6	7.080	48	120.0	48	120	4.63	1826.69
8	x	1	6.750	17	25.0	32	62.5	2.41	1741.59

8	x	2	6.686	33	55.0	36	50	1.97	1726.13
8	x	3	6.472	27	10.0	41	22.5	1.05	1679.41
8	x	4	6.885	12	0.0	38	62.5	2.42	1776.61
8	x	5	6.484	15	0.0	32	25	1.04	1677.00
8	x	6	6.520	32	40.0	40	45	1.76	1682.93
6	y	1	7.442	34	10.0	51	12.5	0.50	1922.28
6	y	2	7.637	43	15.0	54	20	0.78	1970.85
6	y	3	7.471	51	10.0	51	10	0.39	1928.32
6	y	4	7.443	64	10.0	64	10	0.39	1920.59
6	y	5	7.503	54	15.0	60	20	0.78	1936.47
8	y	1	7.394	25	15.0	25	15	0.59	1908.64
8	y	2	7.413	28	10.0	32	12.5	0.48	1912.71
8	y	3	7.363	24	20.0	28	25	0.97	1899.85
8	y	4	7.483	24	10.0	28	15	0.59	1931.75
8	y	5	7.426	23	10.0	31	15	0.59	1916.89
8	y	6	7.205	24	10.0	28	12.5	0.49	1860.47

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12.4 Lever arm test results

Compression test results

Sample No	Weight (kg)	Count 1st crack (-)	Load 1st crack (kN)	In Mpa	Count Failure (-)	Failure Load(KN)	In Mpa
6.y.1	7.442	34	10	0,40	51	12,5	0,50
6.y.2	7.637	43	15	0,58	54	20	0,78
6.y.3	7.471	51	10	0,39	51	10	0,39
6.y.4	7.443	64	10	0,39	64	10	0,39
6.y.5	7.503	54	15	0,58	60	20	0,78
8.y.1	7.394	25	15	0,59	25	15	0,59
8.y.2	7.413	28	10	0,39	32	12,5	0,48
8.y.3	7.363	24	20	0,77	28	25	0,97
8.y.4	7.483	24	10	0,39	28	15	0,59
8.y.5	7.426	23	10	0,39	31	15	0,59
8.y.6	7.205	24	10	0,4	28	12,5	0,49

Lever arm test results

Sample No	Weight (kg)	Failure Load (kg)	Arm (m)	Pressure Area (m^2)	Failure Load (kN)
6.y.6	7,517	33,20	1,25	625	0,33
6.y.7	7,246	39,84	1,25	625	0,39
6.y.8	7,513	46,63	1,25	625	0,46
6.y.9	7,429	46,63	1,25	625	0,46
6.y.10	7,525	33,44	1,25	625	0,33
6.y.11	7,628	53,61	1,25	625	0,53
6.y.12	7,490	39,89	1,25	625	0,39
6.y.13	7,585	33,46	1,25	625	0,33

6.y.14	7,411	33,46	1,25	625	0,33
6.y.15	7,352	39,89	1,25	625	0,39
8.y.7	7,453	49,90	1,25	625	0,49
8.y.8	7,390	56,63	1,25	625	0,56
8.y.9	7,392	42,84	1,25	625	0,42
8.y.10	7,368	42,84	1,25	625	0,42
8.y.11	7,548	42,84	1,25	625	0,42
8.y.12	7,408	42,84	1,25	625	0,42
8.y.13	7,049	49,90	1,25	625	0,49
8.y.14	7,291	49,90	1,25	625	0,49
8.y.15	7,342	49,90	1,25	625	0,49
8.y.16	7,730	49,90	1,25	625	0,49

Sample No	Mpa	weight (kN)	Weight lever arm (kN)	Arm zp	arm CSEB	Failure load CSEB	in Newton
6.y.6	2,92	0,07	0,08	0,90	0,27	1,82	1822,74
6.y.7	3,41	0,07	0,08	0,90	0,27	2,13	2130,04
6.y.8	3,91	0,07	0,08	0,90	0,27	2,44	2444,42
6.y.9	3,91	0,07	0,08	0,90	0,27	2,44	2444,42
6.y.10	2,93	0,07	0,08	0,90	0,27	1,83	1834,03
6.y.11	4,43	0,07	0,08	0,90	0,27	2,77	2767,50
6.y.12	3,41	0,07	0,08	0,90	0,27	2,13	2132,21
6.y.13	2,94	0,07	0,08	0,90	0,27	1,83	1834,77
6.y.14	2,94	0,07	0,08	0,90	0,27	1,83	1834,77

6.y.15	3,41	0,07	0,08	0,90	0,27	2,13	2132,21
8.y.7	4,15	0,07	0,08	0,90	0,27	2,60	2595,69
8.y.8	4,65	0,07	0,08	0,90	0,27	2,91	2906,88
8.y.9	3,63	0,07	0,08	0,90	0,27	2,27	2268,72
8.y.10	3,63	0,07	0,08	0,90	0,27	2,27	2268,72
8.y.11	3,63	0,07	0,08	0,90	0,27	2,27	2268,72
8.y.12	3,63	0,07	0,08	0,90	0,27	2,27	2268,72
8.y.13	4,15	0,07	0,08	0,90	0,27	2,60	2595,69
8.y.14	4,15	0,07	0,08	0,90	0,27	2,60	2595,69
8.y.15	4,15	0,07	0,08	0,90	0,27	2,60	2595,69
8.y.16	0,46	0,08	0,08	0,90	0,27	0,29	286,59

12.5 Drop test results

(days.cement percentage(1=5; 2=7,5; 3=10; 4=12.5; 5=15).#brick)	initial heigth [m]	depth groove [m]	bouncing heigth [m]	mass brick [kg]	gravitational acceleration [m/s^2]	contact time impact [s]	V1 [m/s]	KE without bounce [J]	KE with bounce [J]	Impact Force [N]
voorbeeld steen	*0,45*	*0,002*	*0,010*	*7,6*	*9,788*		*2,9680*	*33,6237376*	*0,8926656*	*17258,2016*
8.1.1	0,45	failure	0,000	7,185	9,788		2,9680			
8.1.2	0,15	failure	0,000	7,338	9,788		1,7136			
8.1.3	0,05	0,003	0,000	7,301	9,788		0,9893	3,787495964	0,214386564	1333,960843
	0,1	0,006	0,005	7,301	9,788		1,3991	7,574991928	0,786084068	1393,512666
	0,15	failure	0,000	7,301	9,788		1,7136			
8.1.4	0,125	failure	0,000	7,232	9,788		1,5643			
8.1.5	0,1	failure	0,000	7,326	9,788		1,3991			
8.1.6	0,1	0,008	0,003	7,327	9,788		1,3991	7,745401008	0,788883436	1066,785556
	0,1	failure	0,000	7,327	9,788		1,3991			
8.2.1	0,125	0,004	0,008	7,394	9,788		1,5643	9,336048888	0,868469664	2551,129638
	0,125	failure	0,000	7,394	9,788		1,5643			
8.2.2	0,125	0,005	0,005	7,447	9,788		1,5643	9,47586068	0,72891236	2040,954608
	0,125	0,006	0,008	7,447	9,788		1,5643	9,548751916	1,020477304	1761,538203
	0,15	0,008	0,005	7,447	9,788		1,7136	11,51681529	0,947586068	1558,05017
	0,2	failure	0,000	7,447	9,788		1,9787			
8.2.3	0,15	failure	0,000	7,207	9,788		1,7136			
8.2.4	0,125	0,005	0,010	7,338	9,788		1,5643	9,33716472	1,07736516	2082,905976

	0,15	0,007	0,008	7,338	9,788		1,7136	11,27642201	1,07736516	1764,826738
	0,175	0,011	0,008	7,338	9,788		1,8509	13,35932798	1,364662536	1338,544593
	0,2	failure	0,000	7,338	9,788		1,9787			
8.2.5	0,175	0,003	0,007	7,422	9,788		1,8509	12,93108341	0,72646536	4552,516256
	0,2	failure	0,000	7,422	9,788		1,9787	#VALUE!	#VALUE!	#VALUE!
8.2.6	0,2	failure	0,000	7,309	9,788		1,9787	#VALUE!	#VALUE!	#VALUE!
8.3.1	0,15	0,005	0,008	7,322	9,788		1,7136	11,10849908	0,931680568	2408,03593
	0,2	0,009	0,005	7,322	9,788		1,9787	14,97855682	1,003348304	1775,767236
	0,3	failure	0,000	7,322	9,788		2,4234	#VALUE!	#VALUE!	#VALUE!
8.3.2	0,3	failure	0,000	7,388	9,788		2,4234	#VALUE!	#VALUE!	#VALUE!
8.3.3	0,25	failure	0,000	7,379	9,788		2,2122	#VALUE!	#VALUE!	#VALUE!
8.3.4	0,2	0,005	0,010	7,325	9,788		1,9787	14,6979055	1,0754565	3154,6724
	0,25	failure	0,000	7,325	9,788		2,2122	#VALUE!	#VALUE!	#VALUE!
8.3.5	0,225	0,007	0,010	7,157	9,788		2,0987	16,25223011	1,190896172	2491,875183
	0,25	failure	0,000	7,157	9,788		2,2122	#VALUE!	#VALUE!	#VALUE!
8.3.6	0,25	failure	0,000	7,243	9,788		2,2122	#VALUE!	#VALUE!	#VALUE!
8.4.1	0,25	0,008	0,080	7,475	9,788		2,2122	18,8766474	6,4385464	3164,399225
	0,25	0,011	0,018	7,475	9,788		2,2122	19,0961433	2,1217937	1928,903364
	0,3	0,015	0,011	7,475	9,788		2,4234	23,0470695	1,9022978	1663,291153
	0,35	0,018	0,015	7,475	9,788		2,6176	26,9248304	2,4144549	1629,960294
	0,4	0,025	0,017	7,475	9,788		2,7983	31,0952525	3,0729426	1366,727804
	0,45	failure	0,000	7,475	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
8.4.2	0,5	failure	0,000	7,563	9,788		3,1286	#VALUE!	#VALUE!	#VALUE!

8.4.3	0,45	failure	0,000	7,447	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
8.4.4	0,4	failure	0,000	7,498	9,788		2,7983	#VALUE!	#VALUE!	#VALUE!
8.4.5	0,35	failure	0,000	7,387	9,788		2,6176	#VALUE!	#VALUE!	#VALUE!
8.4.6	0,3	0,008	0,015	7,504	9,788		2,4234	22,62233882	1,689330496	3038,958664
	0,35	failure	0,000	7,504	9,788		2,6176	#VALUE!	#VALUE!	#VALUE!
8.5.1	0,35	0,008	0,020	7,342	9,788		2,6176	25,72713157	2,012177888	3467,413682
	0,4	0,01	0,010	7,342	9,788		2,7983	29,46403336	1,43726992	3090,130328
	0,45	failure	0,000	7,342	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
8.5.2	0,4	0,008	0,010	7,658	9,788		2,7983	30,58225363	1,349217072	3991,433838
	0,45	0,01	0,010	7,658	9,788		2,9680	34,47999184	1,49913008	3597,912192
	0,5	failure	0,000	7,658	9,788		3,1286	#VALUE!	#VALUE!	#VALUE!
8.5.3	0,45	failure	0,000	7,526	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
8.5.4	0,425	0,006	0,012	7,547	9,788		2,8844	31,83798552	1,329660648	5527,941027
	0,45	failure	0,000	7,547	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
8.5.5	0,425	0,007	0,012	7,618	9,788		2,8844	32,21207309	1,416734696	4804,115398
	0,45	failure	0,000	7,618	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
8.5.6	0,45	0,006	0,020	7,631	9,788		2,9680	34,05965597	1,941997928	6000,275649
	0,475	failure	0,000	7,631	9,788		3,0494	#VALUE!	#VALUE!	#VALUE!
14.1.1	0,05	0,003	0,003	7,23	9,788		0,9893	3,75066372	0,42460344	1391,75572
	0,1	0,005	0,004	7,23	9,788		1,3991	7,4305602	0,63690516	1613,493072
	0,15	failure	0,000	7,23	9,788		1,7136	#VALUE!	#VALUE!	#VALUE!
14.1.2	0,1	0,004	0,005	7,154	9,788		1,3991	7,282428608	0,630210168	1978,159694
	0,15	failure	0,000	7,154	9,788		1,7136	#VALUE!	#VALUE!	#VALUE!

14.1.3	0,125	failure	0,000	7,165	9,788		1,5643	#VALUE!	#VALUE!	#VALUE!
14.1.4	0,125	0,005	0,005	7,472	9,788		1,5643	9,50767168	0,73135936	2047,806208
	0,125	0,007	0,003	7,472	9,788		1,5643	9,653943552	0,73135936	1483,614702
	0,125	0,009	0,002	7,472	9,788		1,5643	9,800215424	0,804495296	1178,301191
	0,15	failure	0,000	7,472	9,788		1,7136	#VALUE!	#VALUE!	#VALUE!
14.1.5	0,125	0,007	0,005	7,156	9,788		1,5643	9,245666496	0,840515136	1440,88309
	0,15	failure	0,000	7,156	9,788		1,7136	#VALUE!	#VALUE!	#VALUE!
14.1.6	0,125	failure	0,000	7,198	9,788		1,5643	#VALUE!	#VALUE!	#VALUE!
14.2.1	0,2	0,009	0,006	7,539	9,788		1,9787	15,42247199	1,10687598	1836,594219
	0,25	failure	0,000	7,539	9,788		2,2122	#VALUE!	#VALUE!	#VALUE!
14.2.2	0,225	failure	0,000	7,315	9,788		2,0987	#VALUE!	#VALUE!	#VALUE!
14.2.3	0,2	failure	0,000	7,227	9,788		1,9787	#VALUE!	#VALUE!	#VALUE!
14.2.4	0,2	failure	0,000	7,184	9,788		1,9787	#VALUE!	#VALUE!	#VALUE!
14.2.5	0,175	0,008	0,007	7,306	9,788		1,8509	13,08653642	1,07266692	1769,900418
	0,2	failure	0,000	7,306	9,788		1,9787	#VALUE!	#VALUE!	#VALUE!
14.2.6	0,175	0,01	0,004	7,366	9,788		1,8509	13,33820548	1,009377712	1434,758319
	0,2	failure	0,000	7,366	9,788		1,9787	#VALUE!	#VALUE!	#VALUE!
14.3.1	0,25	0,01	0,008	7,406	9,788		2,2122	18,84738128	1,304818704	2015,219998
	0,3	0,01	0,011	7,406	9,788		2,4234	22,47187768	1,522288488	2399,416617
	0,35	0,016	0,011	7,406	9,788		2,6176	26,53131365	1,957228056	1780,533857
	0,4	0,017	0,008	7,406	9,788		2,7983	30,22829998	1,8122482	1884,738128
	0,45	failure	0,000	7,406	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
14.3.2	0,4	failure	0,000	7,369	9,788		2,7983	#VALUE!	#VALUE!	#VALUE!

14.3.3	0,35	0,009	0,011	7,451	9,788		2,6176	26,18200929	1,45860776	3071,179672
	0,4	failure	0,000	7,451	9,788		2,7983	#VALUE!	#VALUE!	#VALUE!
14.3.4	0,375	failure	0,000	7,382	9,788		2,7094	#VALUE!	#VALUE!	#VALUE!
14.3.5	0,35	failure	0,000	7,375	9,788		2,6176	#VALUE!	#VALUE!	#VALUE!
14.3.6	0,3	0,01	0,010	7,513	9,788		2,4234	22,79654564	1,47074488	2426,729052
	0,35	failure	0,000	7,513	9,788		2,6176	#VALUE!	#VALUE!	#VALUE!
14.4.1	0,35	0,005	0,010	7,597	9,788		2,6176	26,39759978	1,11539154	5502,598264
	0,45	0,014	0,008	7,597	9,788		2,9680	34,5027783	1,635907592	2581,334707
	0,5	0,017	0,013	7,597	9,788		3,1286	38,44382841	2,23078308	2392,624205
	0,55	failure	0,000	7,597	9,788		3,2813	#VALUE!	#VALUE!	#VALUE!
14.4.2	0,5	failure	0,000	7,388	9,788		3,1286	#VALUE!	#VALUE!	#VALUE!
14.4.3	0,45	failure	0,000	7,478	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
14.4.4	0,4	failure	0,000	7,537	9,788		2,7983	#VALUE!	#VALUE!	#VALUE!
14.4.5	0,35	0,008	0,005	7,324	9,788		2,6176	25,6640577	0,931935056	3324,499094
	0,4	0,014	0,009	7,324	9,788		2,7983	29,67854717	1,648808176	2237,668239
	0,425	failure	0,000	7,324	9,788		2,8844	#VALUE!	#VALUE!	#VALUE!
14.4.6	0,4	0,004	0,009	7,566	9,788		2,7983	29,91862723	0,962728104	7720,338834
	0,425	failure	0,000	7,566	9,788		2,8844	#VALUE!	#VALUE!	#VALUE!
14.5.1	0,45	0,004	0,007	7,586	9,788		2,9680	33,71030267	0,816769448	8631,76803
	0,5	failure	0,000	7,586	9,788		3,1286	#VALUE!	#VALUE!	#VALUE!
14.5.2	0,45	0,009	0,012	7,715	9,788		2,9680	34,66111878	1,58580282	4027,435733
	0,475	0,012	0,010	7,715	9,788		3,0494	36,77552254	1,66131724	3203,069982
	0,5	0,019	0,012	7,715	9,788		3,1286	39,19198398	2,34094702	2185,943737

	0,525	0,023	0,014	7,715	9,788		3,2058	41,38190216	2,79403354	1920,692857
	0,55	0,024	0,011	7,715	9,788		3,2813	43,34527708	2,6430047	1916,178408
	0,575	0,027	0,010	7,715	9,788		3,3550	45,45968084	2,79403354	1787,174607
	0,6	0,029	0,015	7,715	9,788		3,4272	47,49857018	3,32263448	1752,455333
	0,65	failure	0,000	7,715	9,788		3,5671	#VALUE!	#VALUE!	#VALUE!
14.5.3	0,5	failure	0,000	7,503	9,788		3,1286	#VALUE!	#VALUE!	#VALUE!
14.5.4	0,45	0,006	0,008	7,435	9,788		2,9680	33,18484368	1,01883292	5700,612767
	0,5	0,009	0,011	7,435	9,788		3,1286	37,04185402	1,4554756	4277,481069
	0,55	failure	0,000	7,435	9,788		3,2813	#VALUE!	#VALUE!	#VALUE!
14.5.5	0,5	0,01	0,008	7,775	9,788		3,1286	38,811867	1,3698306	4018,16976
	0,55	0,017	0,013	7,775	9,788		3,2813	43,1496639	2,283051	2672,512641
	0,6	0,021	0,015	7,775	9,788		3,4272	47,2591557	2,7396612	2380,896043
	0,65	0,025	0,015	7,775	9,788		3,5671	51,3686475	3,044068	2176,50862
	0,7	0,026	0,012	7,775	9,788		3,7018	55,2498342	2,8918646	2236,219185
	0,75	0,027	0,018	7,775	9,788		3,8317	59,1310209	3,4245765	2316,873978
	0,8	0,028	0,012	7,775	9,788		3,9574	63,0122076	3,044068	2359,1527
	0,85	failure	0,000	7,775	9,788		4,0792	#VALUE!	#VALUE!	#VALUE!
14.5.6	0,5	0,01	0,012	7,785	9,788		3,1286	38,8617858	1,67639076	4053,817656
	0,6	0,013	0,012	7,785	9,788		3,4272	46,71034254	1,9049895	3739,640926
	0,7	failure	0,000	7,785	9,788		3,7018	#VALUE!	#VALUE!	#VALUE!
28.5.1	0,2	failure	0,000	6,829	9,788		1,9787	#VALUE!	#VALUE!	#VALUE!
28.5.2	0,15	failure	0,000	6,932	9,788		1,7136	#VALUE!	#VALUE!	#VALUE!
28.5.3	0,1	0,005	0,008	6,834	9,788		1,3991	7,02357516	0,869585496	1578,632131

	0,125	0,009	0,010	6,834	9,788		1,5643	8,963419728	1,270932648	1137,150264
	0,15	failure	0,000	6,834	9,788		1,7136	#VALUE!	#VALUE!	#VALUE!
28.5.4	0,125	0,007	0,005	6,886	9,788		1,5643	8,896822176	0,808802016	1386,517742
	0,15	0,01	0,008	6,886	9,788		1,7136	10,78402688	1,213203024	1199,72299
	0,15	failure	0,000	6,886	9,788		1,7136	#VALUE!	#VALUE!	#VALUE!
28.5.5	0,125	0,009	0,010	6,946	9,788		1,5643	9,110318032	1,291761512	1155,786616
	0,15	0,013	0,008	6,946	9,788		1,7136	11,08195402	1,427736408	962,2838794
	0,15	failure	0,000	6,946	9,788		1,7136	#VALUE!	#VALUE!	#VALUE!
28.5.6	0,125	0,009	0,005	6,852	9,788		1,5643	8,987028384	0,938943264	1102,885739
	0,15	failure	0,000	6,852	9,788		1,7136	#VALUE!	#VALUE!	#VALUE!
28.7.1	0,15	0,005	0,010	6,995	9,788		1,7136	10,6123943	1,0270059	2327,88004
	0,175	0,01	0,001	6,995	9,788		1,8509	12,6664061	0,75313766	1341,954376
	0,175	0,012	0,010	6,995	9,788		1,8509	12,80334022	1,50627532	1192,467962
	0,175	0,015	0,005	6,995	9,788		1,8509	13,0087414	1,3693412	958,53884
	0,175	0,016	0,004	6,995	9,788		1,8509	13,07720846	1,3693412	902,9093538
	0,2	0,025	0,005	6,995	9,788		1,9787	15,4050885	2,0540118	698,364012
	0,225	failure	0,000	6,995	9,788		2,0987	#VALUE!	#VALUE!	#VALUE!
28.7.2	0,2	0,007	0,008	7,238	9,788		1,9787	14,66502761	1,06268316	2246,815824
	0,225	0,011	0,002	7,238	9,788		2,0987	16,71954838	0,920992072	1603,685496
	0,25	0,02	0,002	7,238	9,788		2,2122	19,12829688	1,558601968	1034,344942
	0,25	failure	0,000	7,238	9,788		2,2122	#VALUE!	#VALUE!	#VALUE!
28.7.3	0,225	0,007	0,005	7,307	9,788		2,0987	16,59285251	0,858250992	2493,014786
	0,25	failure	0,000	7,307	9,788		2,2122	#VALUE!	#VALUE!	#VALUE!

28.7.4	0,225	0,008	0,008	7,198	9,788		2,0987	16,41578759	1,127264384	2192,881497
	0,25	0,014	0,004	7,198	9,788		2,2122	18,59986234	1,268172432	1419,145341
	0,25	failure	0,000	7,198	9,788		2,2122	#VALUE!	#VALUE!	#VALUE!
28.7.5	0,25	failure	0,000	7,054	9,788		2,2122	#VALUE!	#VALUE!	#VALUE!
28.7.6	0,225	0,008	0,010	7,16	9,788		2,0987	16,32912464	1,26147744	2198,82526
	0,25	0,011	0,007	7,16	9,788		2,2122	18,29142288	1,26147744	1777,536393
	0,25	failure	0,000	7,16	9,788		2,2122	#VALUE!	#VALUE!	#VALUE!
28.10.1	0,3	0,008	0,010	7,367	9,788		2,4234	22,20932437	1,297947528	2938,408987
	0,35	0,011	0,008	7,367	9,788		2,6176	26,03105876	1,370055724	2491,010407
	0,4	failure	0,000	7,367	9,788		2,7983	#VALUE!	#VALUE!	#VALUE!
28.10.2	0,35	0,009	0,007	7	9,788		2,6176	24,597244	1,096256	2854,833333
	0,4	failure	0,000	7	9,788		2,7983	#VALUE!	#VALUE!	#VALUE!
28.10.3	0,375	failure	0,000	7,145	9,788		2,7094	#VALUE!	#VALUE!	#VALUE!
28.10.4	0,35	0,009	0,007	6,889	9,788		2,6176	24,20720199	1,078872512	2809,563833
	0,375	failure	0,000	6,889	9,788		2,7094	#VALUE!	#VALUE!	#VALUE!
28.10.5	0,375	0,007	0,006	7,173	9,788		2,7094	26,81996177	0,912721212	3961,811854
	0,4	0,013	0,004	7,173	9,788		2,7983	28,99645081	1,193558508	2322,308409
	0,4	failure	0,000	7,173	9,788		2,7983	#VALUE!	#VALUE!	#VALUE!
28.10.6	0,375	0,009	0,009	7,06	9,788		2,7094	26,53565952	1,24385904	3086,613173
	0,4	failure	0,000	7,06	9,788		2,7983	#VALUE!	#VALUE!	#VALUE!
28.12.1	0,4	0,009	0,008	7,257	9,788		2,7983	29,05189004	1,207535772	3362,158424
	0,425	0,013	0,008	7,257	9,788		2,8844	31,11180401	1,491661836	2507,958911
	0,425	0,016	0,008	7,257	9,788		2,8844	31,32489856	1,704756384	2064,353434

28.12.2	0,425	0,009	0,008	7,262	9,788		2,8844	30,8489179	1,208367752	3561,920628
	0,45	failure	0,000	7,262	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
28.12.3	0,425	0,009	0,005	7,333	9,788		2,8844	31,15052534	1,004855656	3572,82011
	0,45	failure	0,000	7,333	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
28.12.4	0,425	0,008	0,005	7,344	9,788		2,8844	31,12537018	0,934479936	4007,481264
	0,5	failure	0,000	7,344	9,788		3,1286	#VALUE!	#VALUE!	#VALUE!
28.12.5	0,425	0,006	0,012	7,329	9,788		2,8844	30,91832461	1,291252536	5368,262858
	0,45	0,011	0,008	7,329	9,788		2,9680	33,07041217	1,362988788	3130,309178
	0,45	failure	0,000	7,329	9,788		2,9680	#VALUE!	#VALUE!	#VALUE!
28.12.6	0,425	0,008	0,006	7,333	9,788		2,8844	31,07874993	1,004855656	4010,450699
	0,425	0,012	0,009	7,333	9,788		2,8844	31,36585155	1,507283484	2739,427919
	0,425	0,016	0,006	7,333	9,788		2,8844	31,65295316	1,579058888	2077,000753
	0,425	failure	0,000	7,333	9,788		2,8844	#VALUE!	#VALUE!	#VALUE!
28.15.1	0,45	0,009	0,006	7,248	9,788		2,9680	32,56303162	1,06415136	3736,353664
	0,475	0,014	0,011	7,248	9,788		3,0494	34,69133434	1,7735856	2604,637138
	0,475	0,017	0,008	7,248	9,788		3,0494	34,90416461	1,7735856	2157,514718
	0,475	0,018	0,008	7,248	9,788		3,0494	34,97510803	1,844529024	2045,535392
	0,475	0,018	0,004	7,248	9,788		3,0494	34,97510803	1,560755328	2029,770187
	0,475	0,024	0,004	7,248	9,788		3,0494	35,40076858	1,986415872	1557,799352
	0,475	0,025	0,003	7,248	9,788		3,0494	35,471712	1,986415872	1498,325115
	0,5	failure	0,000	7,248	9,788		3,1286	#VALUE!	#VALUE!	#VALUE!
28.15.2	0,5	failure	0,000	7,596	9,788		3,1286	#VALUE!	#VALUE!	#VALUE!
28.15.3	0,5	0,009	0,012	7,482	9,788		3,1286	37,27601234	1,537910136	4312,658053

	0,525	0,012	0,009	7,482	9,788		3,2058	39,32655919	1,537910136	3405,372444
	0,525	0,014	0,007	7,482	9,788		3,2058	39,47302682	1,537910136	2929,35264
	0,55	failure	0,000	7,482	9,788		3,2813	#VALUE!	#VALUE!	#VALUE!
28.15.4	0,5	0,009	0,006	7,435	9,788		3,1286	37,04185402	1,0916067	4237,051191
	0,525	0,016	0,005	7,435	9,788		3,2058	39,37061498	1,52824938	2556,179023
	0,55	0,016	0,005	7,435	9,788		3,2813	41,18995948	1,52824938	2669,888054
	0,55	0,018	0,009	7,435	9,788		3,2813	41,33550704	1,96489206	2405,577728
	0,55	failure	0,000	7,435	9,788		3,2813	#VALUE!	#VALUE!	#VALUE!
28.15.5	0,525	0,01	0,009	7,649	9,788		3,2058	40,05460042	1,422499828	4147,710025
	0,55	0,011	0,010	7,649	9,788		3,2813	42,00117913	1,572236652	3961,219617
	0,575	0,016	0,008	7,649	9,788		3,3550	44,24723149	1,796841888	2877,754586
	0,575	0,021	0,007	7,649	9,788		3,3550	44,62157355	2,096315536	2224,661385
	0,575	0,023	0,005	7,649	9,788		3,3550	44,77131038	2,096315536	2037,722866
	0,6	0,026	0,006	7,649	9,788		3,4272	46,86762591	2,395789184	1894,746734
	0,625	0,03	0,006	7,649	9,788		3,4979	49,03880986	2,695262832	1724,46909
	0,65	failure	0,000	7,649	9,788		3,5671	#VALUE!	#VALUE!	#VALUE!
28.15.6	0,55	0,011	0,004	7,655	9,788		3,2813	42,03412554	1,1239071	3923,457513
	0,575	0,012	0,008	7,655	9,788		3,3550	43,98223118	1,4985428	3790,064498
	0,6	0,019	0,005	7,655	9,788		3,4272	46,37989966	1,79825136	2535,692159
	0,625	failure	0,000	7,655	9,788		3,4979	#VALUE!	#VALUE!	#VALUE!

12.5 Minutes meeting with ASF and NSET in Nepal

<u>Meeting ASF</u>

Date: 11-12-2017
Location: Architects sans Frontieres Kathmandu
Minutes secretary: Rens
Present SSN-team: Rens, Janna
Present ASF Salena Sangnache, Pawan Shrestha

What is team 6 doing and are we working together with Habitat for humanity Nepal?
Team 6 is working together with Build up Nepal now, we are leaving the house in Ratankot and are busy with research on the CSEB bricks. We are also developing a new test method that is cheap and easy. The last team had more contact with Habitat, our team not.
ASF: We also use CSEB, but not interlocking, so maybe we could use the method too.

ASF is building more in traditional way than Build up Nepal?
There are already a lot of organizations that use the CSEB bricks. 3 different companies make the machine. The bricks costs 6 times less and when we test the bricks in a compression test they are better then fired bricks. Only quality control is still a problem.

Results?
Now we made bricks with different compositions to make a hardening curve to know the strength after a few days, still developing the test method. First we had a torque wrench, now trying the drop test again. We are also thinking about a different version of the droptest where we stack bricks on it to make it static and more controlled.

Update of what ASF is working on:
We are still working on the same project but a lot more houses are built now. We are building in 6 or 7 different districts. We use CSEB because it uses less water and also costs are reduced. We promote the technology and are building for the most vulnerable people and helping them with the bricks. They already produces 10.000 bricks, houses are build and people are already living in the houses. We use the not-interlocking CSEB. The machine is very simple to operate. The only problem is curing time and quality control. One of the issues is that people use the bricks before they are fully cured. The pressing machine has had lots of modifications already, 3000 machines are used at the moment. The one Build up Nepal is using is more controlled then ASF is using, but more heavy and difficult to operate. Another difference is that Build Up also is a contractor but ASF only architect and to transfer knowledge, they do not build. We provide details, knowledge and are promoting wood treatment as well. If you do not treat wood it is not usable.

You work with the local way, what are the measures of seismic design you use? Do you get help to build earthquake prove, where does the knowledge come from?
We use the national building code, we do not develop new knowledge and do not want to interfere

with others. One project for example called bottle by bottle, they provide the details themselves. The technology is not local but affordable and we can help them. First they have to agree with the technology, we build one house and look at the response.
We started with dry wall constructions, high in the mountains. With this technology you do not use mortar it is a stone dry wall. This is traditionally what they are following and cement is too expensive to transport. Without plaster you can see the wires and this doesn't look good for the locals so we have to modify the design. We don't know yet exactly how we can make the dry wall structure seismic sound. We don't have a big structural team here. The research is done back in France, they try to improve the designs and test. We are not confident enough about the technology to bring in into mainstream. Therefore we need more help with this technology.
There are already 20 companies working with CSEB. ASF wants to be in the place where the knowledge is most wanted. In the designs we use wooden bans, there are 4 to 8 houses connected to each other.

Last time when team 5 had a meeting with you, you told there were a lot of unexplored opportunities. Are there more opportunities explored now?
Shake table: NSET did tests with a shake table in China, ASF didn't get any funding to do this. They are also working with walls in closed in wires but the government didn't approve it. The test in China was done with a whole building. We have to stick to what the government has approved. They did come up with 2 catalogues. We are also working with CSEB because it was approved by the government. We have been working for a long time on the dry walls and are hoping for an earthquake prove design. There is still nothing in the building code about dry walls.

What are the rules of thumb you use for seismic design?
We have the building code but is not very detailed. If the building code is not followed then the people do not get the grand from the government.

Any questions for us left?
Since SSN is doing research it would be great if we shear our research if we have any helpful output. It would be good to see if there is anything new or if there are any improvements. We will send the report to ASF.

Meeting NSET

Date: 13-12-2017
Location: NSET
Minutes secretary: Rens
Present SSN-team: Janna, Stephan, Jim, Rens
Present ASF: Eputy executive director Dr Ramesh Guragain, Sujan Raj Adhikari

Introduction of Shock safe Nepal for NSET
SSN is a multidisciplinary project of TU Delft, in contact with NSET via Witteveen & Bos.
We are the 6th team of SSN, currently with 3 Civil Engineering students and 1 mechanical engineering student. Previous teams explored what happened in Nepal. Team 4 build a pilot house in Ratankot. We are researching specific the CSEB used in the houses. The quality of bricks can be inconsistent. We are working together with Build up Nepal because of the short period we are actually in Nepal. We made bricks with different ratios of cement and we test these bricks after several days to be able to make a hardening curve. At the same time developing a new test method, which can save a lot of time. To finish the house in Ratankot, we attempt to do a seismic analysis.

What is NSET, it's goal?
NSET is a NGO with 2 main jobs. The first job is to link policy to implementation, related to earthquakes. But it is not only all about earthquakes more about the total, for example also fluids etc. can play an important role. Linking means good guidelines, a good system, information may have not reached community. Our job is to help to bring policy to implementation for example in schools and hospitals. Every time we have good guidelines and codes we advise the central government to have a policy in place. So our job is about linking policy, information and implementation. We can also make the policy if it is technical like reconstruction guidelines. We submit the policy and then the government has to approve this. Sometimes we do not make the policy and only give feedback, this depends on the level.
Our second job activity is to work as a link between community and research institutions. There is good knowledge produced but research stays still in the university, it takes a lot of time to go from there to community. So it is our job to look what is good research and then transfer the knowledge and sometimes change, adapt, or customize it before. Community has to understand what is going on and what level of the problem will be solved. People do not have access to university directly. These are the two areas. We work with a specific system. It is important to first define problems in the field. Sometimes problems are solved by policy, sometimes by technical knowledge.
Sometimes the university doesn't have the capacity or interest for research. In that case we do some research ourselves.
We have one philosophy: to make the link between policy making and implementing. We also publish the results. It is all about generate the knowledge and use it. We are not interested in advanced science or technology but we are interested in using it. So no high tech materials or technology, expensive technology cannot be used in Nepal. The target is to construct houses and make them earthquake prove. We must have very strong evidence to say that something is right. We can accomplish this by testing and doing analysis. This is not the first time CSEB is studied, it has been studied several times, also different times published. The ratio of cement and soil is also been studied in different countries. The contribution to develop a new test method is big. The bricks with a

low strength after a few days do not need a big machine to test. For example the wrench type of test is not 100% accurate but this doesn't matter. NSET did thousands of tests of houses in Nepal to determine properties of brick masonry. Contribution is different bricks is important but for earthquake safety it is more important to have a good system. It is not so much about the materials. One building method we tested is dry stone walls, for a lot of people it is hard to understand that this type of structures can be earthquake prove. It is beyond imagination of the people how to model this structure. But we made the dry stone structure earthquake safe. There are two ways to make it earthquake prove. With concrete you get small cracks. The masonry slides and there is friction, therefore it has some shear capacity. The more sliding the more energy you dissipate and this allows for some movements. The stones are already separated so a very small displacement already tend to dissipate a lot of energy. Then you need something to hold it, that is the idea of the bandage. So we use that and then we are able to get the label. It is very important to understand the model right.

How are we going to distribute the knowledge from SSN?
We have contact with different organizations who are interested. The research is mostly for Build up Nepal, they will spread the results if we will have useful conclusions.

Are we testing only the bricks or fully wall test?
Because: only from testing the bricks it is too hard to get results of the whole house.
We test the bricks and next to this we only want to do a response spectrum analysis. Therefore we do have to know properties of the wall, need it to analyze the whole wall.
When doing micro analysis then the bricks become important. But it does not help in terms of safety. Individual bricks can be used and to show the difference, level of safety and change of safety. Of course with better bricks there is better safety. But you cannot do simulations on this level. It stays difficult to see if there is damage because of the bad quality bricks. Therefore you have to model a whole wall or building. With the same mortar and the same bricks, what is the difference? If you can do this level of research then changing the brick make sense. How much is the influence in overall safety? This is very important for implementation. We can say that good bricks are good, but what is governing? Mortar, bricks.. What we have seen is that with earthquakes not the bricks will fail but the mortar. Increasing bonding makes much more sense for earthquake safety, despite the fact that it is important to have good quality bricks. Take the testing to a higher level. You have to use properties to analyze the whole building. But having the right properties is very important. Within the model shear-, compression-, and tension capacity is very important. Then you can say something about additional safety of good bricks.

Last team tested a small wall including mortar without rebars, is this a useful test?
The test is ok, if test is done here we know the set up and have enough experience. There is a lot of difference between testing at different locations. We test for example here and in Italy, the results differ a lot. That is because of the protocols of testing are very different for example how smooth the surface is made. We did around 5 test here in Nepal and 5 test in Italy. In Nepal we find a very high variation in results so be careful for this as well.
We still want to do response spectrum analysis to know how the structure will behave. The advice of the last team was to look at specific factors that are unknown. Every following team can study different subjects and in the end we do get a really good model. What we miss most: the elastic design spectrum we have in the Eurocode. We can imagine that is very different here in Nepal. Do you have a elastic design spectrum and where/how can

we find this information?

We use the building code of Nepal, there is a spectrum which you have to multiply to get the elastic design spectrum. The code is outdated because we use more modern materials now, so the code changes. It is easy to use the Indian design code, use the highest seismic area, 4. If you are interested more in the spectra: there is a more detailed version of the code but not public available. This one you can copy from NSET.

12.6 Groupchart

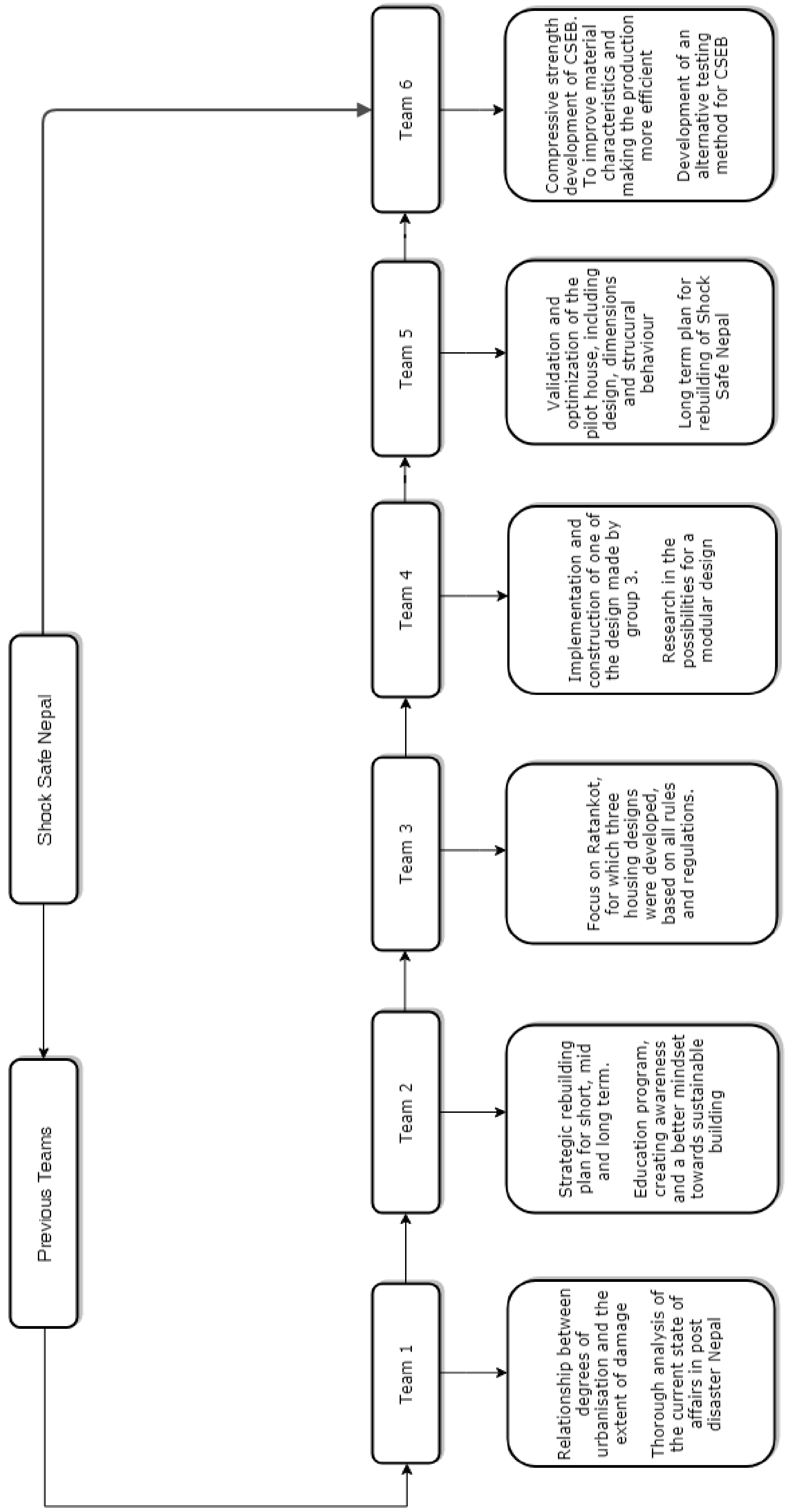

Figure 29: Group chart Teams SSN