1. Introduction

On the 25th of April, 2015, a 7.8 magnitude earthquake struck Nepal, and was followed by a 7.3 magnitude earthquake on the 12th of May. The Government of Nepal (GoN) reported the death toll at approximately 8,790 and about 22,300 suffered injuries [1]. The international community was mobilized and worked together to assist the GoN in relief, recovery and reconstruction.

Ramechhap district belongs to the central region of Nepal, which has over 44,000 households representing a total population of 202,646. According to the GoN, this district was one of the most affected districts out of seven severely hit in terms of house structural damage [2]. The District Disaster Relief Committee (DDRC) reported that 18,693 (42.5%) houses in Ramechhap were completely destroyed and 22,271 (50.6%) were partially damaged, resulting in 181,473 (89.6%) people affected. As per the census conducted by the Central Bureau of Statistics [3], there were 42,327 mud mortar brick/stone houses in Ramechhap, representing the great majority of houses, and thus, a clear sign of the vulnerability of this construction system which made use of locally sourced stone bonded together with mud mortar.

The total number of households in Bijulikot is 1,312. The population is of mixed casts, mainly Brahmin, Chhetri, Janjatis and Dalits. The main source of income is agriculture (mainly maize and millet), making it very difficult for families to have a consistent source of income the full year. Medair chose to work in Bijulikot given the level of destruction found, but also given that it is a very remote location which had not received aid. It is located 32 kms from Manthali, the capital of Ramechhap, and 162 kms from Kathmandu, the country's capital.

Immediately after the earthquake occurred, Medair sent its response team on the 27th of April 2015 and provided emergency shelter kits and water, sanitation and hygiene (WASH) kits to more than 40,000 affected people in the Sindhupalchowk district. Medair also provided tools and technical support to households for demolition through cash for work interventions and cash transfers to support affected households located at higher altitudes, in their preparations for winter.

Later on, from January 2016, Medair provided PASSA (Participatory Approach for Safe Shelter Awareness)[4] training and mason training followed by the construction of two model houses. These trainings covered 12 Village Development Committees (VDCs) of 3 districts (Sindhupalchowk, Ramechhap and Okhaldhunga). From July 2016 Medair started providing technical, financial and social mobilization support to 310 HHs of Bijulikot VDC for their new earthquake resistant house construction, and from May 2017 Medair started supporting the reconstruction of the remaining 990 HHs of Bijulikot VDC.

Although Medair helped in the early stages after the disaster, this paper focuses on the reconstruction phase of the 1,300 houses in Bijulikot.

2. House Reconstruction in Bijulikot – Preparatory Work

2.1 Typical house description

Although there are some brick masonry buildings and a few reinforced concrete buildings (confined masonry), the vast majority of buildings in this area are traditional houses 2-story high plus an attic (prior to the earthquake; one-story plus attic after the earthquake) made of stone masonry joined with mud mortar, and with locally sourced timbers for the roof. A typical house can be seen in Figure 1. These houses are built by self-trained masons using locally available materials, often resulting in poor workmanship. The most common problems observed in the buildings were the lack of through stones (wide stones that go through the full width of the wall), lack of bands (sill, lintel and gable) and stitches, improper opening positions and sizes, lack of bonding between masonry units, irregular configuration, and lack of vertical reinforcement at wall junctions. All these structural deficiencies were compounded by other issues such as construction on sloped ground and on unstable slopes, significantly adding to the seismic vulnerability of the structures.

Medair targeted the reconstruction of all the houses in Bijulikot (1,300 houses) given the high levels of damage observed throughout the town. This process is explained in detail below.

Figure 1. Typical single-family house found in Bijulikot prior to the earthquakes.

2.2 Design of seismic resilient houses

The Building Code of Nepal [5] was published in 1994 but its implementation was still a challenge. People were adopting traditional construction practices which lack resilience to earthquakes. Most of the buildings damaged during the 2015 earthquakes were the result of poor construction methods and lack of engineering design. Therefore, it was imperative to raise awareness of proper implementation of the building code during the reconstruction process so that the same structural weaknesses were not repeated.

Before construction of new houses could start, the Department of Urban Development and Building Construction (DUDBC) reviewed their construction policies, resulting in the publication of a standard house design catalog on October 2015 [6]. This catalog provided a number of pre-approved houses with different typologies and using different materials, including stone and brick masonry, joined with cement or mud mortar, and including ring bands around the house made of timber or reinforced concrete. The catalog provided different alternatives in terms of size, layout and number of stories, providing options to people, while having structural elements to bind the house together and make it more resilient to seismic events. The DUDBC also allowed people to build a unique house, different from those in the catalog, provided that the Nepali Building Code [5] was followed.

Some of the structural elements and safety requirements incorporated in the house models are: ring bands, vertical steel reinforcement at corners and intersections, and geometric limitations in terms of building shape, height and openings among others. Ring bands going around all walls (perimeter and internal) provide out-of-plane resistance to the walls, acting as flexural members in that direction, and binding the house together. Bothara and Brzev [7] suggested that these bands are the most critical earthquake resistant provision in stone masonry buildings, acting as rings that hold the walls together and ensure integral box action, plus reduce the effective wall height and increase the probability of having wall delamination. Ali et al. [8] carried a series of experimental testing on stone masonry houses. They studied three one-third scale houses under simulated earthquakes, in a shaking table, with and without reinforcing bands. The authors recognize the improvement in earthquake resistance achieved by adding reinforced concrete bands when these are used at sill, lintel and roof levels. They concluded that bands provided at several levels are effective in maintaining the integrity of a building, mainly because these elements divide the walls into smaller segments.

Vertical reinforcement was also used at the four corners and at wall intersections to help resist overturning moments at the walls. Special attention was paid to the composition of stone masonry walls, including the requirement of having through stones every 1.2 meters horizontally and every 0.6 meters vertically, in order to keep the wall's cross-section together and avoid delamination. Another requirement was the use of corner stones that stitched together all corners.

The length of the walls was limited to the lesser of 4.5m and 12 times the thickness of the wall, while its height was limited to the lesser of 3m and 8 times the thickness of the wall. Wall thickness was suggested to be 400mm, but not below 350mm. The size and location of wall openings, such as doors and windows, were also prescribed. These openings were required to be away from corners and from other openings at least 600mm, and their width could not exceed 30% of the total wall length.

Other requirements included a limit of 13.5 sq. m. for the size of a room. Use of lightweight materials for the roof and at gable walls was promoted, but in case stone masonry was used at gable walls, special reinforced concrete beams were required to bind these elements.

Most people in the districts where we worked chose stone masonry houses since this is the material they were accustomed to, and given that stone from previous damaged houses could be reused in their new houses. Masons were initially using mud mortar because it was a common practice and was significantly less expensive than cement mortar. However, after a significant effort from Medair, this practice changed and cement mortar was used instead. Medair's push for the use of cement mortar was in order to increase the load bearing capacity of the walls and their durability.

Figure 2 shows the plan view and a cross-section of a typical stone-masonry cement mortar house. Note that the cross-section does not show the attic which nearly all the population included, making the house 1.8m taller at the ridge, and allowing for an extra 24 square meters of space where people could store food. Also note that dimensions are provided in the imperial system as preferred by local masons.

In addition to assisting with the house design, Medair engineers also provided cost estimates so that beneficiaries could be fully aware of the financial implications before starting their house construction. A schedule of materials was then provided so that they could start purchasing the materials needed.

2.3 Cluster formation and financial assistance

The reconstruction process started with community engagement sessions guided by the participatory approach for safe shelter assistance (PASSA) developed by International Federation of Red Cross and Red Crescent Societies [4] at ward level in Ramechhap, which built trust within the local community, and lead to the formation of clusters or small groups of about 10 households within wards. This system of clusters was not new to the rural Nepali culture, in fact, people in this region were already accustomed to working together and helping each other. In this exchange of labor, locally called "Armah Parmah," families living nearby organized themselves to help each other finish similar sets of tasks. This is commonly used in farming on each other's land and was adapted in housing reconstruction, helping us ensure that no one was left behind, and facilitating the distribution of tools that were meant to be shared by members of each cluster.

A major challenge experienced before the works could begin was the fact that banking facilities were not available and people had no previous experience of working with banks. In fact, bank facilities were only available at the district headquarter. Bank accounts were necessary since the assistance by the GoN was provided to beneficiaries' bank accounts by means of direct deposits. In total three installments were provided, each upon completion and government certification of a well-defined milestone: 500 USD were provided for commencement of work, 1,500 USD after completing the plinth band, and a final installment of 1,000 USD after completing the houses. Medair helped the population overcome this challenge by assisting them to open bank accounts. In addition, given that funding was very tight, Medair provided three tractor trips, equivalent to $350, to help each family with transportation costs. Figure 3 shows an illustration of the three milestones used for payments.

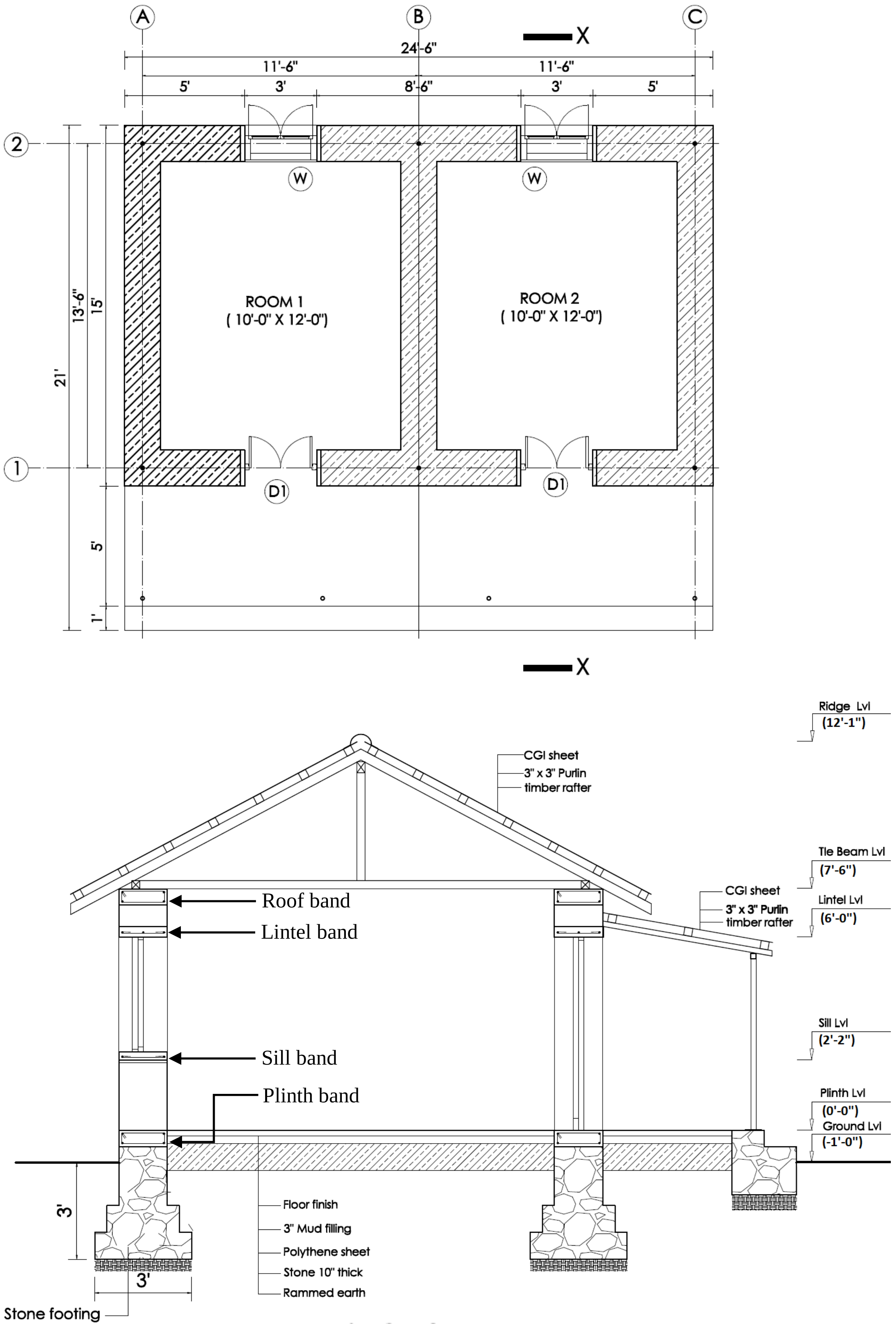

Figure 2. Plan view and cross-section of typical stone masonry house.

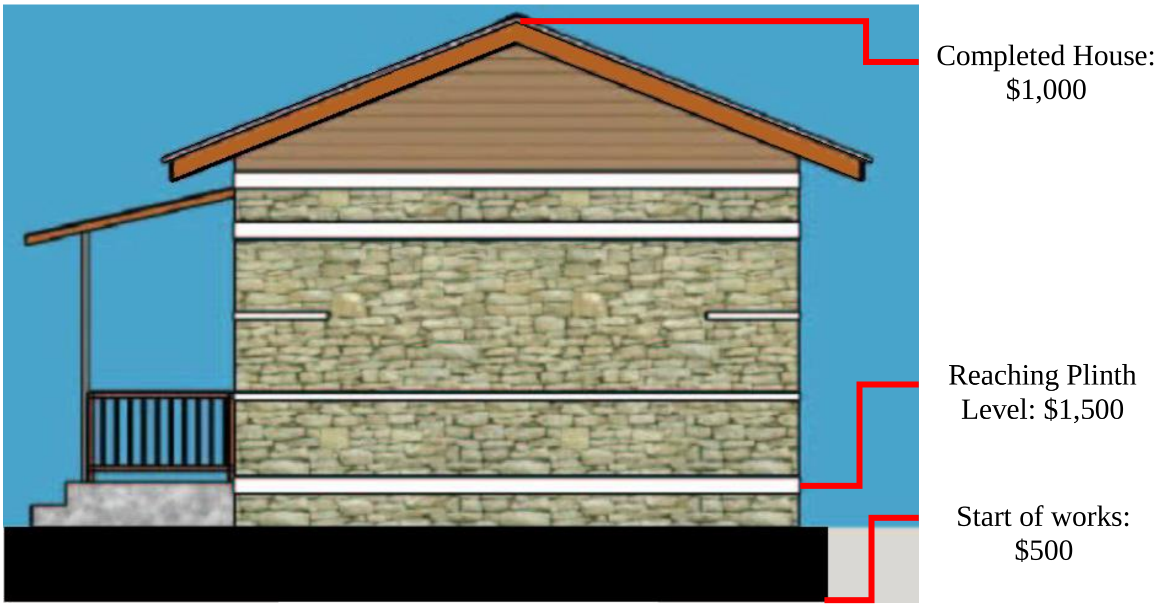

Figure 3. House construction milestones for payment (adapted from [6]).

2.4 Mason Training

One major factor to achieve the desired quality in any construction project is to have the right workmanship. This was even more important given the seismicity of the region. Thus, Medair provided mason trainings in different districts throughout the project cycle. In the beginning, after cluster formation, masons were selected from each ward to be trained by Medair's team of engineers following a curriculum designed by the DUDBC. These seven-day trainings were provided to those who were already working in the construction sector. However, as the project progressed it was clear that the number of trained masons was not enough at Bijulikot VDC to complete the whole VDC reconstruction in the stipulated timeframe, thus, a more in-depth training called "50 days on the job training" was provided to those who wanted to join the construction efforts. Similarly, a two-day refresher mason training was provided to trained masons with the aim of improving their skills. In addition, Medair engineers provided recommendations in areas where they had seen improvements needed during regular project site visits. The mason training was essential to ensure at least one trained mason in the houses where reconstruction was ongoing.

The training curriculum focused on earthquake basics, site selection, building configuration and layout, quality of building materials, construction quality, load bearing building construction, bamboo and timber building construction, reinforced concrete framed structures, periodic repairs and maintenance, alternative building materials, technology and sustainable development, role of mason in earthquake resistant construction, Nepal Building Code (NBC), and a hands-on component that included seismic elements demonstration in a model house construction.

The training enhanced the knowledge and skill for construction of earthquake resilient buildings, focusing on the use of quality materials and other necessary seismic requirements outlined by the NBC. It also increased the commitment and responsiveness among the participants to enforce the NBC, making the reconstruction process a little easier. As a result, all the houses were approved by the government and received all three installments of construction financial assistance and completion certificates. Figure 4 shows one of the masons' groups at the end of a hands-on training.

Figure 4. Hands-on training provided to masons.

2.5 Demolition and Cost Estimates

The first step in the reconstruction was to demolish unsafe houses and to classify materials that could be reused such as stone and timbers. Reusing materials played a crucial role in allowing beneficiaries to save money and be able to finish the construction of their houses since the government only provided 3,000 USD per household, which was not sufficient to finish a house. It should be noted, however, that not all beneficiaries chose to demolish their old house as some preferred to keep it for storage and or as cattle shed.

Figure 5. House ready for demolition.

After demolition of damaged houses, Medair engineers provided support regarding the selection of land. As most beneficiaries did not have an option but to build in the land they already owned, it was often necessary to do some land improvement before construction could begin.

3. Construction and Quality Assurance

3.1 Construction

Once construction started, Medair engineers supervised the progress on a daily basis, to ensure quality workmanship and compliance with the agreed standard design. Construction started with the layout, excavation, stone compaction, vertical reinforcement erection, stone laying at foundation, and plinth beam construction. Government engineers would perform an inspection once the plinth beams had been poured, and if the required quality was achieved, the house owner would be eligible to receive the second installment. Figure 6 shows the foundation work, with a layer of compacted stone in preparation for the reinforced concrete footing, on the left, and the plinth level finished on the right.

Figure 6. Excavation for foundations, left; construction up to plinth level, right.

After completing the construction of the foundations, the floor was filled with small stones and compacted. Then, wall construction began by laying stones, ensuring that through stones were properly placed, followed by the sill band, intermediate bands and lintel bands, all placed with proper reinforcement details and a 1:2:4 ratio of cement, sand and aggregate. Figure 7 shows the construction of walls up to sill level, on the left, and Medair engineers performing an inspection of the full wall on the right.

After construction of the roof band, a timber girder was placed horizontally at the center of the wall, spanning the full length of the house. Timber joists were then placed perpendicular to the girder, every 600mm, and wooden planks were placed above. The floor was then finished with a 75mm mud layer. The joists were anchored to the walls through steel rebar placed on the roof band to ensure a proper connection. Wall construction for the attic continued, including an intermediate band after 600mm of wall construction from the roof band, followed by the attic ring beam, built after another 600mm of wall height. The roof structure was then built making use of 3 king posts that supported the ridge girder. Roof rafters were then installed spanning between the ridge girder and the attic ring beam. Purlins were nailed to the rafters and the corrugated iron sheets (CGI) were finally installed.

Once the roofing was completed and latrines were also built, a final inspection from a government engineer would take place. If this inspection was approved, the house owner was eligible to receive the final installment and the house completion certificate. This was the case for all the houses built in Bijulikot.

Figure 7. Construction of a house up to sill level, left; inspection of completed walls, right.

3.2 Quality Assurance

During the construction phase, Medair took the role of ensuring quality of the construction was achieved. Although, the GoN had to inspect each house before each new installment was fulfilled, the reality on the ground was that given the massive reconstruction undertaking, fewer staff than needed were able to visit the project. For this reason, Medair engineers visited frequently to ensure DUDBC house designs were being followed and to ensure high quality workmanship and quality materials were being used in the construction. These engineers used a set of checklists to verify compliance before each submittal for payment.

4. Lessons Learned

A number of lessons were learned throughout this program. This section highlights some that were directly related to the house reconstruction project.

The amount of funding provided by the GoN for the new houses was set to 3,000 USD, independently of the family size and needs. This led to a house selection that was basically controlled by the cost of construction, resulting in most people choosing a small one-story plus attic house with only two rooms. A funding distribution that considers the size of the family could be explored in future interventions, as it is commonly done in other contexts.

Furthermore, this amount of funding was hardly enough to construct an earthquake-resilient house in accordance with the Nepal National Building Code. Thus, families were at times finding ways to reduce the construction cost, and at times would try to use materials of less quality. The quality assurance program established by Medair, along with many measures designed to reduce costs (but not quality), were key to finalizing construction while satisfying quality standards.

Another factor affecting construction costs was the sudden demand for goods. With the reconstruction process across the 14 most affected districts creating high demand for labor and resources, increases in the price of construction materials and the daily wage of masons led some of the people to consider deferring construction in the hope that inflated prices would reduce, effectively causing delays in the reconstruction. This issue was further compounded by the monsoon season, when the extraction of sand was halted for almost three months. During that time people were forced to buy sand at a higher price if they wanted to continue construction. Medair managed this situation as much as possible through sharing of materials among cluster members until demand could be met with sufficient supply and by advising homeowners to stockpile sand in advance of the monsoon.

A similar event that caused difficulties in the supply was the ban on heavy vehicles travelling on the BP Highway (the main arterial route from Kathmandu to Manthali) for several months during mid-2018. This situation gave rise to huge scarcity of material in Manthali and the proliferation of black market tactics by suppliers. The many supply chain challenges prompted Medair to provide each family with three trips of tractor transportation. Through field coordination between social mobilisers, technical staff and logistics teams, the overall demand in the field was met while making supply more convenient and efficient. Helping address these barriers to access construction materials helped accelerate the reconstruction process and meet the tight budget.

Further to the financial and supply chain challenges explained above, other programmatic challenges include the fact that the GoN did not put in place specific plans for the demolition of earthquake damaged houses. Thus, many people were reluctant to demolish their old vulnerable houses, and instead, preferred to keep them for storage or as cattle shed. This is unfortunate as a future earthquake could destroy these vulnerable buildings and cause further injury and death.

Also, the Government deadline for reconstruction was extended more than three times. In the first instance, community members were very motivated to meet the deadline. However, since the deadline was extended a second and third time, people were beginning to anticipate extensions and the motivating factor was reduced.

Finally, the initial training provided to masons was a "seven-day mason training" intended for experienced masons. However, for these very experienced masons to "forget" their habits and learn new technologies was a challenging task. The 50-day on the job training proved to be more efficient and should be rolled out from the initial days so that masons learn in a practical way through building a house.

5. Conclusions

The two earthquakes of 2015 caused significant loss of life and damage to the infrastructure in Nepal. The housing sector was greatly affected, requiring substantial aid from the GoN and from external agencies. Medair helped throughout the emergency relief stages and then focused on the reconstruction of Bijulikot, Ramechhap, one of the most affected districts. The project had a significant number of challenges, some very unusual when compared to day-to-day operations in developed countries. Some of these challenges included the remoteness of the project location, the absence of sufficient masons and the fact that people did not own a bank account where they could receive GoN payments for the reconstruction of their houses. This location also had benefits, such as the commonly used method of working together in agriculture, locally called "Armah Parmah." This method was successfully employed in the reconstruction efforts, making sure that no one was left behind.

The GoN put significant efforts in building back better programs, and, while this slowed down initial reconstruction efforts, it increased the earthquake resilience of the housing sector. To enforce this earthquake resilience, the GoN provided funding only to those home owners that adhered to the Nepali building codes. This was achieved by providing a catalog of house options from which standard, pre-approved designs were selected.

Medair's work consisted mainly in supporting house owners in the reconstruction, paying special attention to the areas where the process could slow down the response. Some of these areas included helping people open bank accounts so that they could receive the finances from the GoN, providing more detailed construction plans and costs estimates so that people could plan properly, helping with the demolition of unsafe houses, training masons to have the skills needed to build the houses, including the earthquake resilient techniques which were new technologies unknown to this region. Medair provided a great emphasis in a quality assurance program, to ensure that earthquake resilience was achieved, and that house owners would satisfy the building code, hence be eligible for GoN funding.

In addition to the outcomes already mentioned, this project also had other significant impacts in the community. First, after successful construction of all latrines at individual houses and public toilets, the VDC was declared Open Defecation Free (ODF). Medair had been providing education on hygiene and sanitation through video presentations, street dramas, sanitation and hygiene trainings, and orientation to the community on how to build, maintain and use their toilets. The eager involvement of the community made it possible to declare Bijulikot VDC an ODF area.

Medair also encouraged the community to construct improved cooking stoves (ICS). As a consequence, most of the houses adopted these stoves after construction of their new house. The impact is significant as the stoves burn less wood and emit smoke outside the house, creating a cleaner, healthier living environment.

6. References

[1] GoN (2015): Post Disaster Needs Assessment, Vol. B: Sector Report. National Planning Commission Nepal. Singha Durbar, Kathmandu

[2] GoN (2015): Nepal Disaster Report 2015. The Government of Nepal, Ministry of Home Affairs (MoHA) and Disaster Preparedness Network-Nepal (DPNet-Nepal). Kalimati, Kathmandu, Nepal. ISBN No: 978-9937-0-0324-7.

[3] GoN (2012): National Population and Housing Census 2011. National Planning Commission Secretariat Central Bureau of Statistics Kathmandu, Nepal. November, 2012.

[4] IFRC (2011): Participatory Approach for Shelter Assistance. International Federation of Red Cross and Red Crescent Societies, Geneva, Switzerland.

[5] NBC (2015): Nepal National Building Code - NBC 203, Guidelines for Earthquake Resistant Building Construction of Low Strength Masonry. Government of Nepal, Ministry of Physical Planning and Works, Department of Urban Development and Building Construction, Kathmandu, Nepal.

[6] GoN (2015): Design Catalogue for reconstruction of earthquake resistance houses. DUBDC, Government of Nepal.

[7] Bothara, J and Brzev, S (2011): A TUTORIAL: Improving the Seismic Performance of Stone Masonry Buildings. Earthquake Engineering Research Institute. ISBN: 978-1-932884-48-7.

[8] Ali, Q, Naeem, A, Ashraf, M, Alam, B, Rehman, S, Fahim, M, and Awais, M (2010): Shake Table Tests on Typical Stone Masonry Buildings Used in the Himalayan Belt, Paper No. 1414, Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering, Toronto, Canada.

