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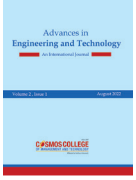

Reassessing the Building Construction System and Quality Issues in Relocated Settlement after the Gorkha Earthquake

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Abstract

This paper assesses the reconstruction process in a mountainous village that typically represents the dominant location of damage by the Gorkha earthquake of April 25, 2015. The pre- and post-earthquake scenarios are presented comparatively. The structural system is found to be mostly compliant as per the new guidelines set by the government; however, deficiencies in terms of construction system and structural characteristics were significant in the reconstruction. Thus, the reconstructed buildings with several deficiencies could be still seismically vulnerable. It is recommended that the performance of reconstructed buildings after the Gorkha earthquake shall be re-assessed for necessary risk management planning. Also, this study provides insight into the construction practice in after-earthquake reconstruction and areas of poor workmanships in such work.

Keywords: Gorkha earthquake; reconstruction; resettlement; structural deficiency; brick-in-cement masonry.

1. Introduction

TThe Gorkha earthquake of April 25, 2015, damaged over a million buildings in Nepal (National Planning Commission Nepal, 2015) . The structural vulnerabilities and deficiencies of Nepali buildings have been comparatively well understood for several decades (Chaulagain et al., 2018; Gautam et al., 2016, 2018) ; however, no significant progresses were made at least for masonry buildings in Nepal until the 2015 Gorkha earthquake. Thus, the devastation was noted to be very high even during the Gorkha earthquake, especially in mountainous regions. Stone masonry buildings, that were the most abundant construction system in rural hilly and mountainous areas of Nepal, are highly vulnerable to even minor to moderate shaking (Adhikari & Gautam, 2019; Gautam, 2018), thus, the damage occurred during the Gorkha earthquake in stone masonry was within the expectation boundary. It is imperative to assess the progress made especially after an earthquake to note the evolution of construction system. Thus, this paper aims to identify the changes and assess the underlying vulnerabilities in the reconstructed buildings.

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Apart from direct impact due to the Gorkha earthquake, the Thami settlement with about 78 families of Bosimpa village and Buma village at Suspa Kshamawati were also challenged by huge landslide that creeped the entire settlement. Suspa Kshamawati lies at altitude of about 1850 m from MSL on ward-1 of Bhimeshwor municipality of Dolakha district and is about 15km north of Charikot. Thami are the ethnic group having their own lifestyle, tradition, religion and culture, mostly engaged in agriculture as their main occupation. Due to high risk of further slide, as identified by experts from then National Reconstruction Authority (NRA), and the poor economic condition of the people, the entire settlement was planned to be relocated to the nearby new place at Pani-pokhari under one of the "Integrated Settlement" program of the NRA. Relocation is often considered as opportunity to reduce the vulnerabilities and improve the livelihood of the people; however, it may disrupt the existing balance of life of some community.

According to Shelter Cluster Nepal (2015), there were 99% of load bearing masonry buildings in Dolakha district. The same report reports that, about 44% of the houses were completely destroyed along with 28%, 23% and 5% buildings sustaining heavy damage, moderate damage and minor damage respectively.

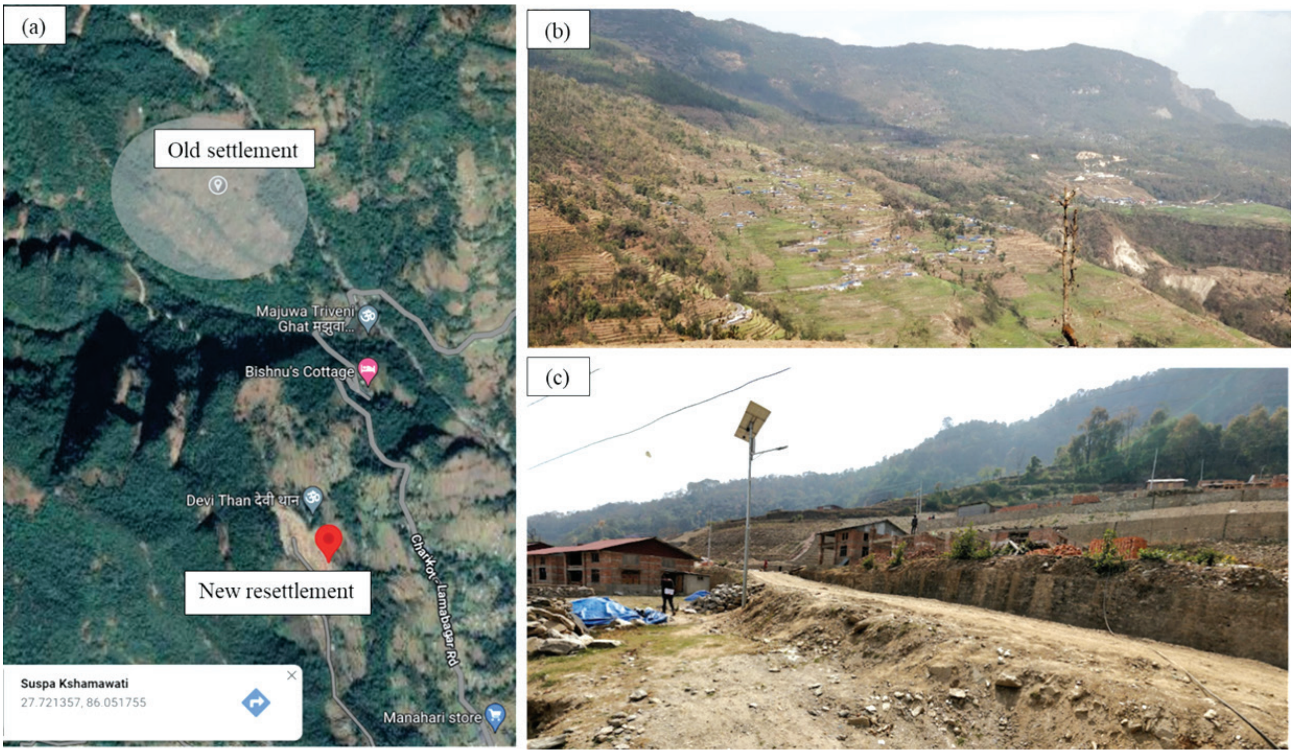

Figure 1. (a) Location of the old and new settlement, (b) The old settlement area, (c) The new settlement area.

2. Post-earthquake scenario of the settlement

All the buildings in the old settlement area of Bosimpa were severely affected. During the field visit at site on March 2021, it was observed that most of the buildings were cleared off and temporary shelter with CGI and timber from old buildings were constructed at the same plinth (Figure 2). Few buildings were retained with their original ground floor (Figure 3), and a first floor was reconstructed with CGI wall and roof in timber frame (Figure 4).

Figure 2. Half height of old building was retained to rebuild CGI sheeted two-storey building.

Figure 3. (a) Ground floor of old building was retained for continued use (b) Reconstructed toilet block with some timber reinforcement.

Figure 4. Reconstructed two storied buildings by building adding light timber frame structure over old first storey.

As there was significant mass movement with creeping of entire village area of Bosimpa, the villagers were afraid of staying there. Further, as per the villager, there was a large stone on the hillside of the village that had high risk of sliding down in aftershock or heavy rainfall. Hence, the villagers made the temporary shelter on the site of Pani-pokhari away from the old settlement, having areal distance of about 1KM and foot trail distance of about 1.6 km. However, they also partially rebuild the earthquake damaged houses in for temporary shelter. They will stay at their farm and old house in day-time and stay at new temporary shelter at Pani-pokhari at night. This way, they continue their occupation of farming and cattle rearing.

3. Resettlement masterplan

NRA conducted detailed study of the site for the reconstruction suitability. However the old village site was considered inappropriate for the residential area by the then NRA finding high susceptibility to landslide and decided to build an aggregated resettlement for the Thani community of Bosimpa and Bhume at the Pani-pokhari as an alternate safe residential area. Buma village lies on the valley side of the Pani-pokhari area, and those villagers were also living in temporary shelter at Pani-pokhari area. The masterplan of the re-settlement program prepared by NRA is as shown in Figure 5 (source NRA). Also, to connect the locals with old agricultural land and other development objectives, a motorable road was under construction to connect the Pani-pokhari and Bosimpa (Figure 6). The road is intended to continue to the next geographical area beyond Bosimpa. The plots were mostly between 1000 to 1700 square feet, prepared in terraced manner the natural slope. The masterplan includes existing community hall, and new playing area, and open spaces.

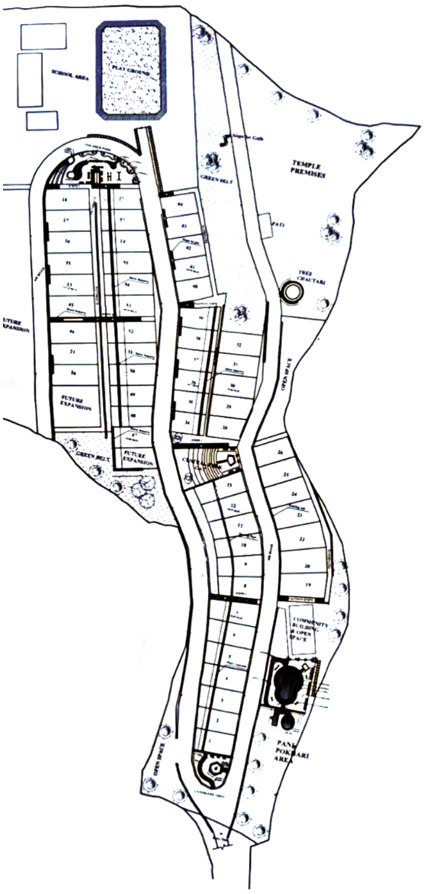

Figure 5. Masterplan of the proposed resettlement location.

Figure 6. Ongoing road construction in old settlement.

4. Geographical setting

The previous settlement area of Bosimpa is a terraced land in high slope of hills. The villagers had cultivated crops on the land and built the houses sparsely per their ownership of land (Figure 7).

Figure 7. Old settlement of Bosimpa

Pani-Pokhari area, identified as suitable place for the relocation was also a terraced land, just under stiff rocky cliffs. The area was developed per the master plan. The local claimed that, during the temporary shelter construction after earthquake and the construction of new building per the master plan, significant trees were cut from the adjacent forest at the foot of the cliff.

Figure 8. New Settlement area of Pani-Pokhari (a) Site located at the foot of cliff, (b, c) The steep terrain of the site (d, e) Retaining wall used for slope stabilization (f) Rock exposure at a site (g) Steep slope for a plot even after retaining wall (h) The lower side to the settlement, with a catch drain and steep terrain.

Figure 8 shows that the relocated site is also not a flat site, but has significantly sloping ground, that require massive retaining infrastructures for development as settlement area. The limitation usually observed in aggregate settlement in hilly area is the availability of sufficient flat land, and the same is also observed in this resettlement. While various engineering measures such as retaining wall, catch drain and others were implemented at the site, several plots were still having high slope, leading to difficulty in building construction.

5. **Building typologies**

While all of the building in old location were unreinforced stone masonry buildings, all the buildings in new location are brick-masonry with reinforcements closely matching the standard design per DUDBC (2015) BMC2.3 model (Figure 9). Some of the typical building forms are as shown in figure.

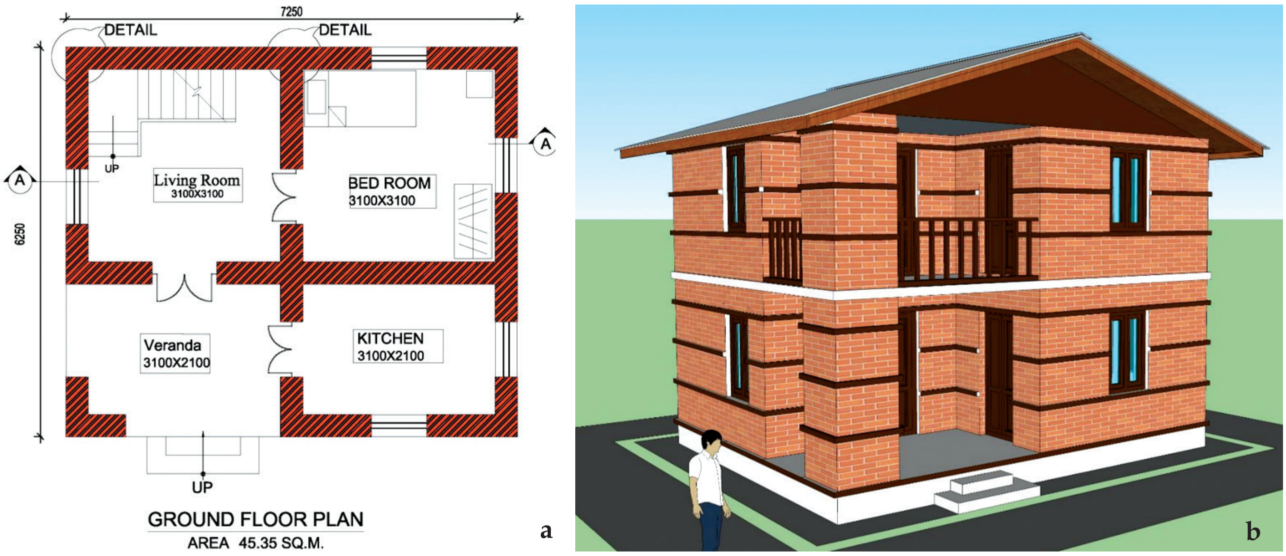

Figure 9. BMC2.3 model building from NRA design catalogue I (a) Plan and (b) Isometric view

As the minimum wall thickness in ground floor in 230 mm for one story building but 350mm at ground floor of two story building per the NRA design catalogue, the adopted type design for the Pani-pokhari was of One plus Attic with 230m thick brick wall. Initially, attic needed to be too low not higher than 0.9m at edges but later owners were allowed to construct upto 1.2m high wall in attic. However, several buildings, specially on the valley-side of the road were built completely two storied with same wall thickness of 230 mm. An isolated brick column is provided in verandah, against *provision of L-shaped wall in the design catalogue. Vertical rebars of 12 mm are provided at each corner and junction of walls, in a mortar filled cavity of 100x100 mm embedded in wall, while 12 mm vertical bars are also embedded on wall at sides of openings. Plinth beam, sill band, lintel band, dowel band, roof band and eaves band are also provided as per the specification of the NRA design catalogue in most of the cases. The openings were so adjusted that, the lintel band and floor band are common. The village committee (formed among the Thani community who required resettlement) decided to adopt similar housing typology for all the houses (see Figs. 10-13) in the resettlement. Later a support of 30,000 numbers of machine made well finished façade bricks were made available to construct the brick-exposed façade. However, several variations can be seen in the constructed buildings depending on the requirement and resources of individual owner. The early constructed building didn't received the façade bricks and were building with hand-made bricks of poor surface finishing.*

Figure 10. (a) One storey plus attic construction with brick wall in attic above veranda (b) One story plus attic construction with open structure above veranda.

Figure 11. (a) Two story construction (One plus tall attic) with brick wall in attic above veranda (b) Two storey construction with open structure above veranda.

Figure 12. Two storey construction with missing dowel band in first floor

Figure 13. (a) Two storey construction (One plus tall attic) with brick wall in attic above veranda and opening in front and back only in attic (b) Complete two storey building built on valley-side of road with single band at mid-height level.

6. Structural details

6.1. Building foundation

The foundation and below-plinth wall were constructed in stone masonry with little or no mud. As the people of the community were living in stone masonry building for long time, they have locally skilled masons to work in stone. Stone being available at the site at no cost, it was opted for use in the foundation and wall upto plinth. Figure 14 shows some of the plinth wall, that are constructed without binder, stone unit not strongly interlocked. In most construction, it is usual practice of construction worker to give less priority in proper laying of masonry unit in sub-structure work compared to super-structure work. Chances of stone unit displacement in the below-plinth wall inducing differential settlement of superstructure is seen in the site. It can be improved by providing next cascading wall outside the plinth wall, or partially improved by proper pointing and plastering of the exposed plinth wall. The risk will be lesser under the ground due to confinement action of the soil. No concrete or protection of vertical rebar was identified below the plinth.

Figure 14. The plinth wall construction in dry stone

6.2. Plinth construction and vertical reinforcements

An RC plinth beam was constructed in all the building. The vertical rebars at corners, junctions of walls, and jambs of the openings (doors and windows) were also erected from the foundation base (Figure 15). The plinth beam was only about 3-inch (75mm) thick

Figure 15. Plinth beam construction and laying of vertical rebars

6.3. Wall construction

All walls were constructed with brick in cement mortar (Figure 16). Walls were typically nine-inch (230mm) thick equal to one brick thickness with 14-inch by 14-inch corners and junctions to accommodate 4-inch by 4-inch mortar filled cavity for rebar (figure 17d). In addition to plinth band, and floor band, reinforced concrete bands are provided at sill level and as dowel at mid-height level of windows. Separate lintel level was not necessary as the openings are upto the floor or roof/eaves band (Figure 17).

Figure 16. (a) Constructed wall in the buildings (b) Some vertical rebar terminated with insufficient development length.

Figure 17. (a) Discontinuous band in attic. (b) Use of toothed construction practice

Steel and cement are the most expensive material of the construction. In some buildings, some steel rebars were found to be terminated without sufficient anchorage. Few inches of rebar were exposed over the top band that indicate only about there to four inch of anchorage in concrete band which is significantly low against the standard provisions of about sixty times the bar diameter. Also, some bands were found to be discontinued at windows (figure 17a) as it was provided above the sill level that shows the poor understanding on construction details among owners and construction workers. Also, toothing was widely adopted in the construction (figure 17b), although mason training was done in that area that encourages building with corners and junctions first as seen in demo wall (see figure 17c)..

6.4. Floor construction

Flooring structure are typically timber joists with rare use of steel box sections. Timber planks are provided over the joists as a floor (Figure 18). Some old timbers from owners' old houses were used, while every family have obtained some timber for the reconstruction from the adjacent forest (Figs. 19, 20).

Figure 18. (a) Typical floor joist and timber plank floor system (b) Splice of floor joist near the support.

Figure 19. (a) Splicing of offset floor joist and use of old timber (b) Grooving of floor timber

Figure 20. (a) Steel box section as floor joists (b) Typical timber joist flooring

Timber joists are confined at supporting wall from sides with two layers of brick (figure 18a), that can impact on moisture balance of the timber and durability. Further, such packer bricks are often loose in place and can fall from its position during strong earthquake shaking. Also, the splicing of floor joist was poor. A joist was found to be spliced near support with simple half-cut overlap (figure 18b). Similarly, some longitudinal joists were not in same alignment and spliced with short cross joist that significantly increase load in the adjacent joists (figure 19a). However, floor timber planks were found to be constructed with semi tongue and groove system with half-cut overlap for proper sealing of the joint (figure 19b).

6.5. Roofing structure

Roofing was constructed in timber frame in all cases. Timber frame was constructed by providing timber rafter supporting on wall at outer edge of the building and over the vertical timber post at the ridge-line of the building (figure 21). Timber purlins are provided over the rafters in three lines on each of the two sloping surfaces. Vertical posts are stabilized with short timber braces at base (figure 23b). However, diagonal bracing on the roofing plane as specified in NRA design catalogue was not found at site. End rafters were tied with vertical rebar from the building corner (figure 22b and figure 23a). Intermediate rafters were tied with vertical rebar, only when it is close to the vertical rebar from the opening jambs (Figure 21). In some cases, the vertical rebar was bend around the timber, and in few cases, timber were drilled to pass through the vertical rebar for anchorage, and in some other cases, gabion wires were used to tie timber with bent vertical rebar (Figs. 22-26). Gabion wires were widely used to tie other timber members of roofing structure with the bands as well such as in figure 23b.

Figure 21. (a) Roofing structure and floor joists. Rafters are anchored by bending the vertical rebar around it. (b) Fixing appropriately cut gable sheet before fixing roofing sheet.

Figure 22. GI wire used to tie the rafter with timber band at eaves and with vertical rebar.

Figure 23. (a) Tying of rafter with vertical rebar (b) Tying of rafter with GI wire from eaves band, bracing of vertical post of roofing structure.

The rafter (inclined member) and bottom member of roofing frame were connected in various ways. Timber wedges were often used for the better connection as in figure 23a, but in few cases, the contact area was very less and tied with GI wire that may allow significant relative displacement of member at joint in case of ultimate loading due to wind or earthquake, leading to relatively poor performance of the roofing structure. In some cases, as shown in figure 24a, there was no horizontal member at eaves level that could lead to poor performance of the roofing structure and increase the toppling risk of the brick column.

Some good practices such as providing additional timber piece with groove in the wall plate the lock the rafter (figure 25a) and providing groove in the rafter to lock the purlin (figure 25b) were also observed. Due to use of old pre-owned timber, several splices were required, including in rafters and purlins such as observed per figure 26. Some splices were poorly constructed as in figure 25b and figure 26b, where purlin which is a bending member had splicing with poor bending resistance, however splices such as in figure 26a and 26c had good resistance.

To avoid drippling of dew from the roof, people used timber of tent sheet under the CGI sheet (figure 24b). People often store the grains and other agricultural product on the attic or upper floor that would be significantly affected by the water-droplets if formed under the CGI sheet

Figure 24. (a) Completed roofing structure, with rafter tied in vertical rebar. (b) Use of old and new timber in roofing structure, vertical rebar left unanchored, and wall in attic constructed only upto 4′ height, remaining to be constructed in timber frame and light partition of CGI or timber.

Figure 25. Provision of groove in wall plate for anchoring rafter and groove in rafter for proper anchorage of purlins.

Figure 26. (a) Extension of rafter and (b, c) Splicing of Purlin

6.6. Roofing sheet

All of the houses used red-colored CGI sheet for the roof (figure 27). However, in the gable, some houses have similar CGI sheet as roof, while many other have uncolored CGI sheet managed from their old houses (figure 27c). At the ridge, some houses used separate plain GI ridge cover while several other used the extension technique that do not require ridge cover (figure 28). The extension technique is economical, but the sealing quality at ridge is slightly inferior to that obtained from ridge cover.

Figure 27. (a, b) Identical roofing but additional short portion of CGI near ridge is distinctly visible (c) Use of old CGI sheet in gable with poor aesthetics

Figure 28. (a) Roof with ridge cover (b) Roof without ridge cover using overlapping technique.

To maintain the similarity, and also as an additional aid, a fixed quantity of colored CGI sheets was provided to each house, which was slightly not sufficient. Hence, owner required to manage the deficient CGI sheet. Further the size of the CGI sheet from the support was not per the optimum size fit for the site. Hence, a short portion of CGI needed to be added by the owner, that has distinct visual odds as seen in figure 27. All the roofing sheets were anchored with metal screws, screwed to timber purlins.

6.7. Concrete and mortar quality

The quality of concrete was found to be compromised in several cases as shown in Figure 29. Honeycombing and rebar exposure were commonly observed in many reconstructed buildings. In few cases, very poor quality of concrete was observed which could be scrapped off even by finger nails as in fig 29(f).

Figure 29. Various concrete defects in reconstructed houses (a-e) honeycombing and exposure of rebar in bands (f) very poor-quality powdery concrete easily scratchable by hand, (g) sand stockpiling with vegetation (h) prepared mortar for construction.

6.8. **Rebar condition**

Almost all the building were under-construction. People have started living only in few buildings without complete finishing of the construction works. However, construction of several other building had just started, and other several were constructed upto plinth and left for a while, mostly due to deficiency in budget for continuity of work (figure 30). However, the vertical rebars provided from the foundation were not well protected, and most of such rebar were found to be heavily corroded at the base near plinth (figure 31). Vertical rebars were also provided on the sides of windows and doors, that were anchored from the plinth. However, as such bars needed to be positioned before laying the doors and windows, the rebar were found to be offset from their required positioned in some cases and were not properly embedded in wall and exposed as in figure 31a. As in figure 31b, most of such bars were provided in the brick masonry wall at the center of wall thickness through the mortar joint. The durability of such bar cannot be entertained due to high porosity and permeability of regular mortar and bricks, and the bar are even more vulnerable to corrosion in long run near the plinth.

Figure 30: Vertical rebar left unprotected at plinth

Figure 31: Corrosion of vertical rebar near plinth

Figure 32: (a) Jamb rebar exposed on window side (b) rebar embedded in concrete wall in mortar

7. **Sanitary system and other infrastructures**

The original building plan included only living space with the assumption of separate outdoor toilet. However, due to limited space most owners constructed toilet attached to one of the wall of the building. As there was no proper and uniform design of the toilet available to them, and as it is considered a element of poor sanitation and less importance, toilet construction often involves less importance, and poor workmanship. As in figures 33, brick, block or stone whatever is easily and cheaply available or in stock was used for the toilet without proper bands and provision of vertical rebars. Further, these toilets are poorly connected to building having weak joint ant connection. Construction against retaining wall as in figure 33-c could lead to differential stress in the building transferred from the toilet masonry that could have unforeseen adverse effect. The roofing (figure 33-b) of toilets are also poorly anchored, and all the construction are intended to be finished with minimum cost with relatively poor quality. To minimize the cost, separate septic-tank were not built, but rather, a combined septic tank and soak pit was used, mostly constructed from dry stone masonry (figure 33d). In such terraced land, significant chance of leaching of the soakpit can be expected on the valley-side that could hamper the environmental condition after few years of use.

Figure 33: (a) Brick masonry toilet, (b) Block masonry toilet, (c) Stone masonry toilet, (d) Septic tank cum soak-pit.

As a part of building structures, other important infrastructures were also being developed, such as electric lines, road, drainage, retaining walls, water-supply, parks, etc. Figure 34a shows an open parapet for general assembly of the community, figure 34b shows an temporary arrangement for water-collection and distribution and figure 34c shows a children's playing ground in the resettlement, indicating that masterplan was developed from multiple perspective of societal requirements.

Figure 34: (a) Open parapet, (b) Temporary water collection and distribution system (c) Children's playground, (d) Significant reduction of section of chain due to friction in the swing of playing ground.

However, few issues were observed on those construction works as well. Figure 34d shows the anchorage system of children's playing swing which has been severely deteriorated due to continuous use and in the verge of breaking. Use of such very simple anchor system against standard system of anchorage using ball-bearings could lead to severe accidents without any pre-indication. As generally observed, the electric poles were also found to be titled (figure 35a), due to lack of proper anchorage in ground. Similarly, the workmanship of stone masonry works in retaining walls were not observed to be good in many cases, especially when they are not adjacent to road such as in figure 35(b).

Figure 35: (a) Tilted electric transmission pole (b) Stone masonry retraining wall of poor workmanship

Figure 36: (a) Poor quality mortar in drain that is easily scrapped by shoes (b) the drainage ended in the nearby area without erosion control measures, (c) Damaged drainage and obstruction by stone in early stage of construction, (d) Poor quality of stone masonry work in drainage.

Similarly, the stone-masonry work on roadside drainage was found too poor. As observed in figure 36a, the mortar in drainage was too fragile that it can be easily scrapped with shoes which could be due to either use of very weak mortar of no curing of the cement-work of the both. Figure 36b shows ending of drainage without any downstream protection work. Required effort was not observed in drainage construction, as the rock was not properly removed in the drainage construction as shown in figure 36(c) leading to reduced drainage capacity. Similarly, the workmanship of stone-masonry in drainage was found to be the poorest. Stones were not laid in compact way, and proper line, level and facing and finishing as observed in figure 36(d). Also, the significant damage in the drainage masonry in this early stage of construction as in figure 36(c) and 36(d) and easily scrapable mortar indicate very poor strength of these structures.

8. **Conclusions**

Although reconstruction in Nepal is almost complete by the end of 2021, studies point out several defects and deficiencies of reconstructed buildings. Aiming to identify the deficiencies of the reconstructed buildings, a case study is presented in terms of pre- and post-earthquake scenarios of typical mountainous neighborhood in central Nepal. Field studies-based evidence are reported in this paper considering the pros and cons of the reconstruction system. Also, resettlement aspects are reported for a rather integrated settlement. The observations highlight that although good masterplan and geometrical compliance is met during the reconstruction process, there exists a wide array of discussion related to quality of construction, and achieving the desired goals including accepted level of disaster resilience. Although several fallacies are found in all types of construction over the country at various degrees, the reconstruction program though NRA was expected to have much better supervision and construction quality. However, the construction in this resettlement was also found to follow the general trend and included many fallacies. Hence, the dilema of whether the intended level of disaster resilience and sustainability was achieved or not has remained. Future studies should incorporate numerical modeling and field tests to better characterize seismic vulnerability and deficiencies of such reconstructed buildings and structures after the Gorkha earthquake, that may be useful in identifying the vulnerability of such structures with some construction defects and planning of disaster risk management

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Conflict of interest

Not declared by the author(s).

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