Making Schools Safer for Earthquakes

Effectiveness of Retrofitting: *Case Studies from Nepal*

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MAKING SCHOOLS SAFER FOR EARTHQUAKES

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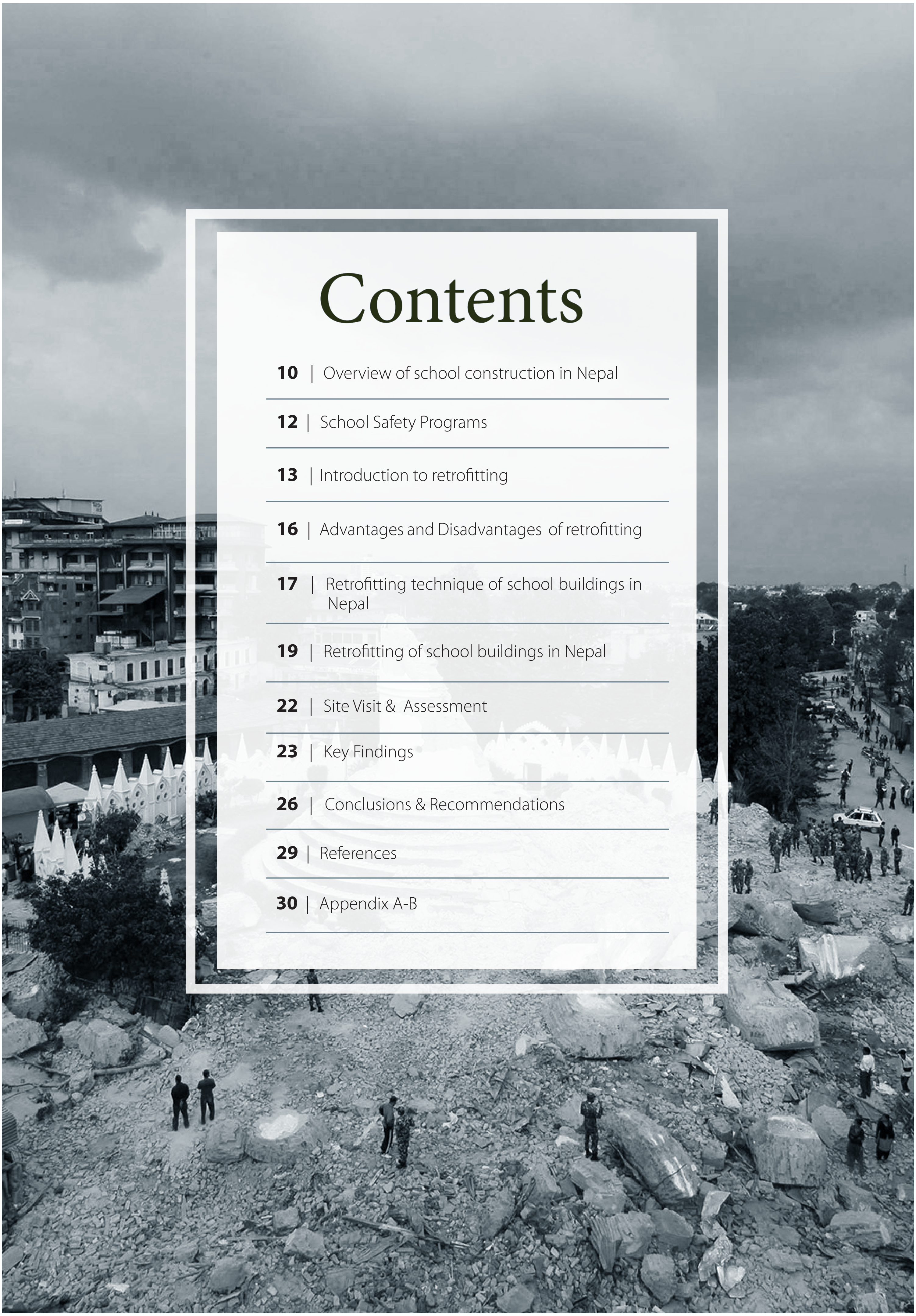

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Foreword

The earthquake and its aftershocks which struck Nepal in April 2015 were a devastating event that served as an eye-opener for policymakers, engineers and the general public on the necessity of having safe buildings and structures that are disaster-resilient. This is specifically true for providing safe learning environments for all school children.

Nepal is a developing country at risk of experiencing intense earthquakes. Seismically weak infrastructure and poor construction techniques specifically of school buildings endangers and disrupts the lives of youth. Their safety and continuity of education is paramount, not only for the parents but for the long term progress of the nation.

Modern engineering techniques like retrofitting can serve as an effective solution to design and construct safer school buildings and mitigate the impact of earthquakes.

The government of Nepal has launched the School Sector Development Plan (SSDP) in July 2016 to prioritize the reconstruction and recovery work in the country. This is an excellent step to advance the retrofitting of all remaining vulnerable school buildings to ensure they function and protect the lives of children and serve as safe-havens and community shelters when most needed.

This report is an overview of the performance of retrofitted school buildings and non-retrofitted buildings during the earthquake as evaluated and assessed by AIT Solutions. Based on our team's observation, key recommendations are provided.

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Executive Summary

Schools are an important symbol of a country's educational and national prestige, they are not only a learning environment for children but also serve as a community hub and shelter during emergencies. Both children and school staffs deserve a safe and secure learning environment.

The lack of awareness among developers about seismic risk and the potential of severe earthquake in the past, requires a skeptical performance evaluation of existing buildings to find out the capacity of the existing buildings against seismic demand.

Various experts of Asian Institute of Technology (AIT) provided a comprehensive review of techniques and retrofit design of existing masonry and concrete buildings in the past, facilitated to increase the capacity of vulnerable schools buildings. The primary objective was to bring to attention effective techniques practiced worldwide in the field of structural health assessment and rehabilitation of damaged buildings. The report provided useful guidelines and recommendations for formulating a rehabilitation strategy and choice of retrofitting methods.

The 2015 earthquake in Nepal revealed the vulnerability of school buildings and how it endangers the lives of children and teaching staffs. It disrupts their education and in the long resulting in socio-economic loss for the country. Most of the school buildings in affected areas like Gorkha, Sindhupalchowk, Dolakha, Nuwakot and part of Kathmandu valley suffered significant damage, rendering them unfit to use. The data shows an estimated 870,000 children will be unable to return to schools, according to the Education Cluster (the coordinating body for humanitarian education activities), comprising UN agencies, non-governmental organizations (NGOs), and other stakeholders (USAID fact sheet 16).

The damage in some of the school buildings was so severe that it may have killed and injured students, if they had been in schools during the earthquake. Such challenges can be minimized and avoided, if appropriate construction methods are used in the initial planning and construction phase. The responsibility of the management bodies is to make school safe for both students and the public since schools are an important structure in the community often serving as shelter during crisis, making it imperative they provide the security needed.

In 2010, Ministry of Education incorporated the school building seismic retrofitting program in the annual national plan and program with adequate budget for seismic retrofitting of 15 school buildings starting from the fiscal year 2011/2012. The concept was jointly formed by the government, ADB and NSET for reducing seismic vulnerability of school buildings in Kathmandu Valley. About 200 school buildings have been retrofitted since led by the government inside Kathmandu valley and an overall of 300 throughout the country. NSET served as national consultant for providing technical assistance to Department of Education (DoE).

The aim of this report is to highlight the benefits of retrofitting school buildings and the urgency of retrofitting in existing school buildings to prevent loss of lives and ensure the continuity of education post-disaster.

Abbreviations

ADPC	Asian Disaster Preparedness Centre
AUDMP	Asian Urban Disaster Mitigation Program
DoE	Department of Education
FEMA	Federal Emergency Management Agency
GHI	GeoHazards International
IS	Indian Standard
KVERMP	Kathmandu Valley Earthquake Risk Management Project
Mw	Moment magnitude scale
NBC	Nepal Building Code
NGO	Non-Government Organizations
NRRC	Nepal Risk Reduction Consortium
NSET	National Society for Earthquake Technology
RC	Reinforced Concrete
SESP	School Earthquake Safety Program
SIDA	Structural Integrity and Damage Assessment
URM	Unreinforced Masonry
USAID	United States Agency for International Development
USGS	United States Geological Survey

Background

On Saturday, 25 April 2015 at 11:56 local time, a Mw 7.6 magnitude earthquake as recorded by Nepal's National Seismological Centre (NSC) and Mw 7.8 magnitude on USGS, struck Barpak in the historic district Gorkha, about 76 km northwest of Kathmandu. The earthquake magnitude was the greatest recorded in Nepal in the last 80 years. The catastrophic earthquake was followed by more than 300 aftershocks greater than magnitude 4.0 (as of 7 June 2015) as shown in figure 2.5. Four aftershocks were greater than magnitude 6.0, including one measuring 6.8, 7.3 magnitude on USGS, which struck 17 days after the first with the epicenter near Mount Everest. There were over 8,790 casualties and 22,300 injuries according to the government.

Overall, an estimated 8 million people were affected by this earthquake in almost 31 districts. Among the affected districts, 14 were declared 'crisis-hit' for the purpose of prioritizing rescue and relief operation. The neighboring 17 districts were declared partially affected (GoN).

Thousands of school were severely damaged or destroyed by the earthquake. Over 32,000 classrooms were totally destroyed or damaged and are unusable. Approximately 15,000 classrooms suffered minor damage. The data shows an estimated 8,70,000 children will be unable to return schools because of minor damaged classrooms and psychological impacts. An estimated 1.5 million children were directly affected by the disaster, leaving 1 million children without permanent classrooms. Gorkha, district of epicenter, alone got 90 % of the 500 schools severely damaged, affecting 75,000 children (Save the Children). The damage in some schools was so severe, that it may have killed and injured many students if the earthquake occurred during school hours.

(a) *(b)*

Figure1: *(a) Survey data from Education cluster (the coordinating body for humanitarian education activities) showing the approximate estimate of damage in the earthquake (b) Completely damaged Deepjyoti School in Gongabu, Kathmandu lacking proper seismic details.*

The primary objective is to bring in to attention, the retrofitting technique used in the vulnerable masonry school buildings in Nepal. The study highlights the performance of retrofitted and non-retrofitted school buildings in April 25, 2015 Gorkha earthquake. The study covers the schools inside the Kathmandu valley only. Further objectives include providing useful recommendations for formulating a retrofitting action plan and action process for retrofitting of school buildings in the future.

**Findings by NSET reveal, that over 66 percent of the Kathmandu valley's public schools are likely to collapse if they were to experience intensity IX shaking.*

Overview of school construction in Nepal

A significant proportion of schools in the country are constructed following the advice of local craftsmen and mason-leaders. Professional engineers are not consulted at any stage in this construction practice. The owner-builder and the crafts-persons are unaware of the possible disastrous consequences from an imminent earthquake.

The construction of schools in Nepal is based on a community driven approach with incremental and non-engineering basis. Seti Education and Rural Development Project was the basis for the construction of school buildings. Most of the school buildings from earlier days are of adobe construction, wooden framed buildings, rubble stone or brick with mud mortar. Unreinforced masonry construction has been broadly used as a typical construction practice.

The construction practices lack engineered technologies and earthquake resistant design, a study in Nepal reveals that only 10 percent of construction is based on engineering techniques. Low construction budget in the past and present makes the material and workmanship poor. Consequently, this means that school buildings in Nepal are extremely vulnerable to earthquake risks.

Masonry has been the structural typology most used on the construction of schools since it is based on locally available materials and construction technologies well known by the local community. About 63% of masonry school buildings are made of stone masonry as per SIDA, 2016 data. Among these stone masonry buildings, the majority is laid on mud mortar and more than a half are made of rubble stone.

Figure2: *Typical load bearing masonry school building which experienced moderate shaking in Kavrepalanchowk, it became unsafe due to major cracks in unreinforced partition walls.*

The post disaster damage assessment of school buildings in earthquake affected districts (Dhading, Dolakha, Gorkha, Nuwakot, Rasuwa and Sindhupalchowk), the building materials used are shown in the chart below.

Building Materials of Schools accoding to SIDA Data Phase I

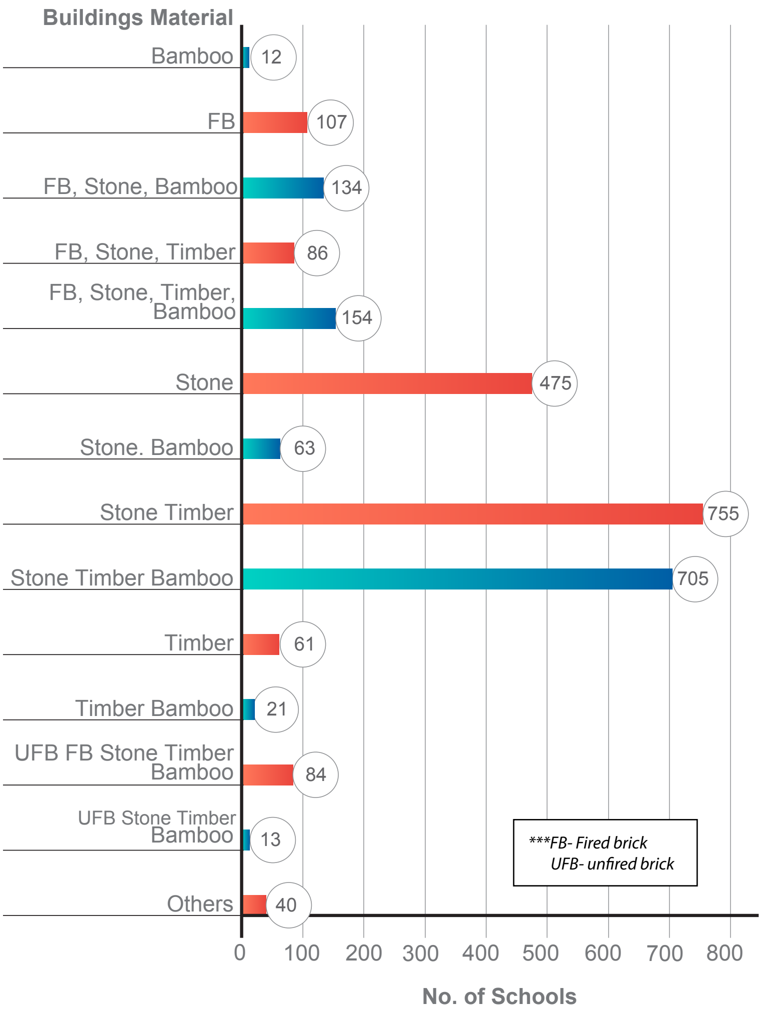


Figure 3: *Classification of building materials in the six earthquake affected districts shows majority of the construction practice was adobe construction techniques. The lesson learnt from these construction practices raise the need of program strategy for the safer school buildings construction and retrofitting of existing vulnerable school buildings in Nepal (Source: SIDA Data Phase II 2016).*

More than 70% of the school buildings in Nepal are constructed by the local craftsmen provided by the community, without any rational design of strength (Source: SIDA 2016).

Findings by NSET shows, over 66 percent of Kathmandu valley's public schools are likely to collapse if they were to experience an earthquake of shaking intensity of IX and if the disaster occurs during school hours in Kathmandu Valley, an estimated damage of 29,000 deaths (students, teachers and administrative staff-12%), 43,000 seriously injured (18%), total collapse of school buildings (66%), partial collapse (11%), and 23% of the buildings are expected to suffer from minor to moderate damage (ADPC 2003).

School Safety Programs

As part of school safety, Kathmandu Valley Earthquake Risk Management Project (KVERMP) was launched from 1st September 1997 to 30th December 1999 which was jointly implemented by NSET and GHI. This project was part of ADPC and AUDMP, with core funding by the office of Foreign Disaster Assistance of USAID (NSET 2000).

SESP is one of the disaster risk reduction programs that has conclusively demonstrated its technical, economic, social and political feasibilities and has become the most attractive programs for funding by government and by small or large funding agencies and international development partners (NSET-KVERMP, 2010).

Nepal Risk Reduction Consortium (NRRC) was formed in May 2009 to support the Government of Nepal in developing a long term disaster risk reduction action plan for implementing important strategic actions suggested in the National Strategy for Disaster Risk Management (NSDRM). The consortium developed five areas of immediate intervention for disaster management in Nepal which included seismic safety of schools and hospitals was one of the five priority areas identified in the flagship programs. The flagship was led by Ministry of Education and coordinated by ADB, included SESP as one of the program (Acharya at. al. 2015).

In 2010, Ministry of Education incorporated school building seismic retrofitting program in the annual national plan and program with adequate budget for seismic retrofitting of 15 school buildings starting from the fiscal year 2011/2012 (Dixit 2015). The government, ADB and NSET jointly developed the concept paper for school vulnerability reduction in Kathmandu valley. The concept paper highlighted that among 1200 school buildings in Kathmandu valley about 900 school buildings require immediate intervention.

Out of which 700 buildings need retrofitting and remaining 200 need to be demolished and reconstructed. Government developed action plan to retrofit 260 school buildings in the Kathmandu valley supported by ADB and Government of Australia by 2015 (Acharya at. al. 2015). NSET served as the national consultant for providing technical assistance to the Department of Education (DoE). The retrofitted program stepped its limit from 3 schools per year to more than 150 schools per year after 2010 (ADB/GoN, 2010).

SESP started as a program to retrofit the vulnerable school buildings based on the survey from NSET. The Office of Foreign Disaster Assistance (OFDA), the U.S. Agency for International Development (USAID), provided funding. The National Society for Earthquake Technology (NSET-Nepal) and GeoHazards International, GHI-USA, were the two main partners in the implementation process.

Introduction to retrofitting

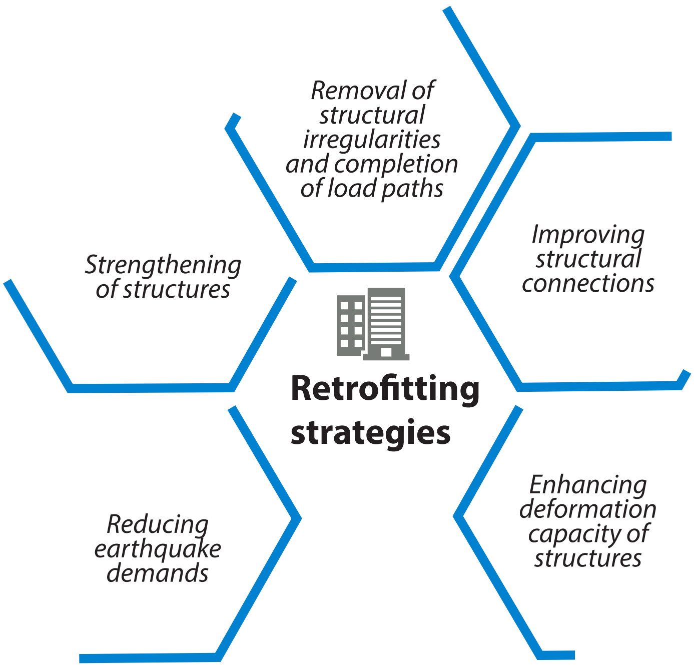
Around the world there are numbers of structures that are vulnerable to seismic activity. These structures are vulnerable to both moderate and strong earthquakes and are seismically weak structures requiring disaster resilient upgrades ATC 40 defines, retrofitting as the basic overall approach to enhance the probable seismic performance of the building or reduce the existing risk to an acceptable level (ATC, 1996).

In many cases, the demolition and reconstruction of the structures can not be practically feasible due to its cultural, social, historical, time for new construction or economic aspects. The seismic risk to the occupants can be significantly reduced at an affordable cost by any positive intervention aimed to increase the structural integrity. It refers to measures or process carried out to restore or enhance the load-carrying capacity and/or performance of a structure or its components. These measures may vary depending upon intended purpose, type of structural component and extent of damage, and are not conceived or foreseen in the original design of a structure.

The appropriate retrofit strategies should satisfy the following condition:

Capacity > Seismic demand

The strategies of retrofitting should comprise of the following considerations:



The retrofit or rehabilitation strategies can be broadly classified as:

Local retrofit	Global retrofit	Combination of global&local retrofit
Enhancement of the capacity and performance of individual components, which in turn enhance the performance of the overall structure or system	Enhance the overall performance of the system by modification of the structural system itself, either by altering, removing or adding one or more component or subsystems	Combination of global and local retrofit results in the optimum solution

Many retrofitting techniques have been developed currently around the world. Some of the conventional retrofitting techniques are surface treatment, textile reinforced mortar (TRM), Ferro cement, steel wire meshing, fiber reinforced polymer (FRP), and concrete jacketing. The techniques used should cover all the demands of the structures, should be simple, economic and easy constructed using local manpower.

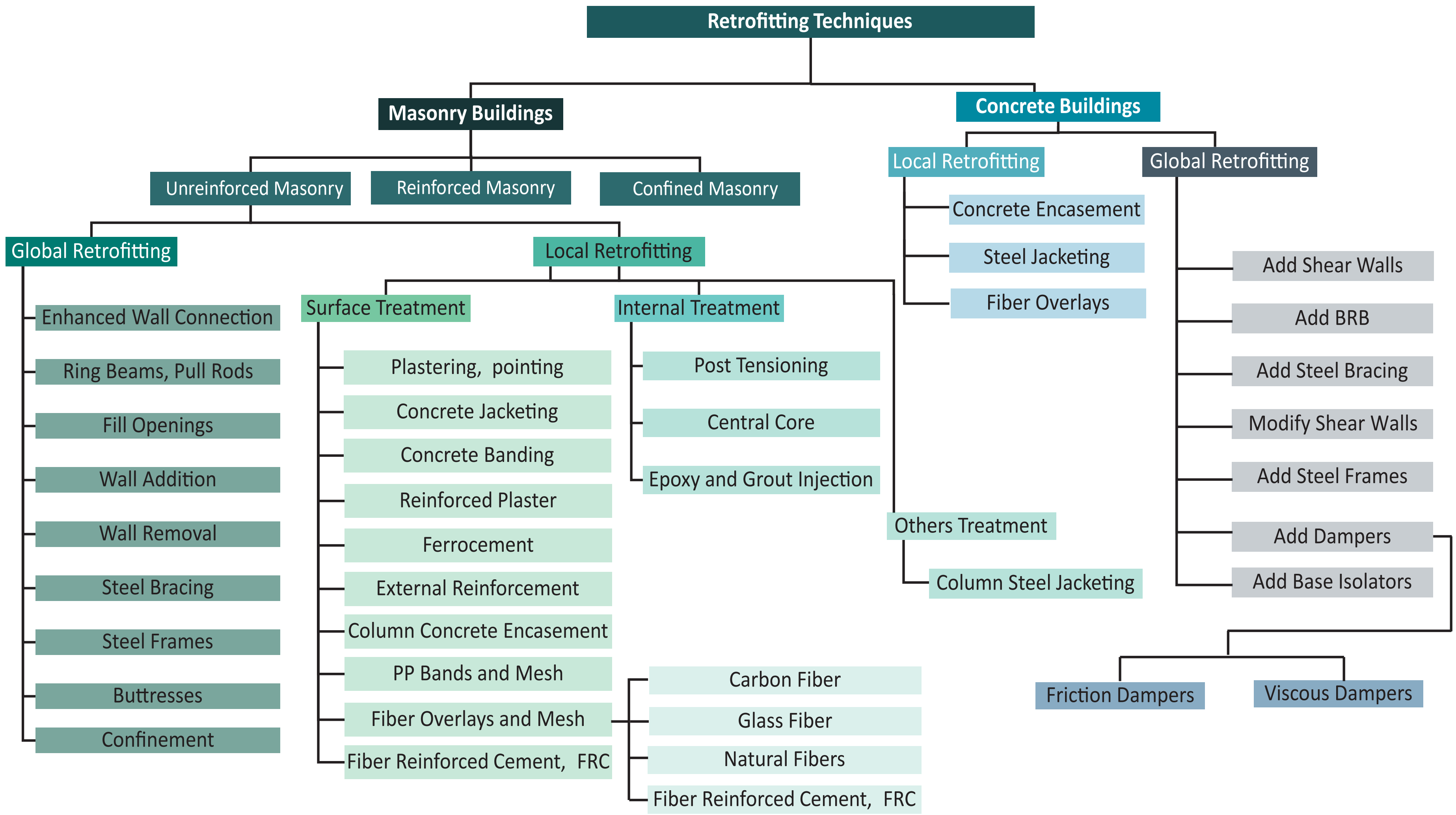


Figure 4: *A chart showing retrofitting techniques used around the world for masonry as well as RCC buildings for local and global retrofitting.*

Advantages and Disadvantages of retrofitting

The majority of the schools, retrofitted are originally constructed using low quality materials, vulnerable to earthquakes. Structural integrity in the earthquakes binding materials, load path discontinuity, connections, age of buildings, heavy roofs and lack of seismic band are major shortcomings of masonry buildings. Retrofitting technique proves an effective solution for these types of vulnerable buildings.

After the site visit of the school buildings, we can summarize the significance of retrofitting in the old masonry school buildings inside the Kathmandu valley.

Advantages:

- Conventional materials with easy construction techniques by locally available manpower and resources.
- Increase the global capacity of building.
- Increasing the local capacity of the structural and non-structural components.
- Significant increase of strength and ductility.
- Reduce deformation demand.
- Cost-effective in comparison to modern technologies like FRP.

Disadvantages:

- Difficult for quality control in rural areas.
- Bonding issues may arise between old masonry and new concrete overlay.
- Relatively, concrete has higher strength than the old masonry, thus special care should be given to specify the strength of overlaid concrete.

Retrofitting techniques for school buildings in Nepal

According to Department of Education (DoE), around 200 school buildings have been retrofitted in 3-districts of Kathmandu valley. The summary of the completed works is shown in the chart below.

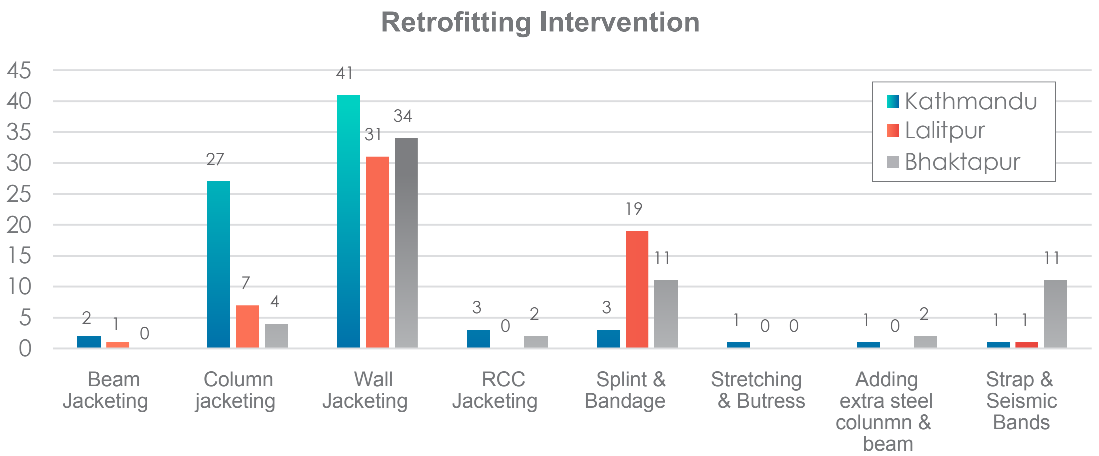


Figure 5: *Retrofitting intervention by World Bank survey (SIDA) shows retrofitting techniques in Kathmandu valley.*

Recent survey on school buildings inside Kathmandu valley by World Bank (SIDA 2016) after Gorkha earthquake shows majority of the retrofitted school buildings perform well in the earthquake as compare to non-retrofitted school buildings.

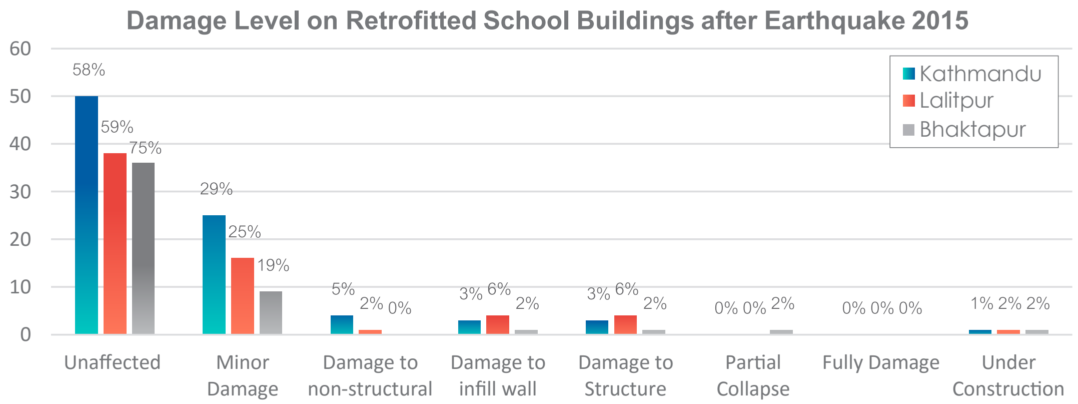


Figure 6: *Damage state of retrofittted blocks of school buildings in Kathmandu valley (Source: SIDA 2016)*

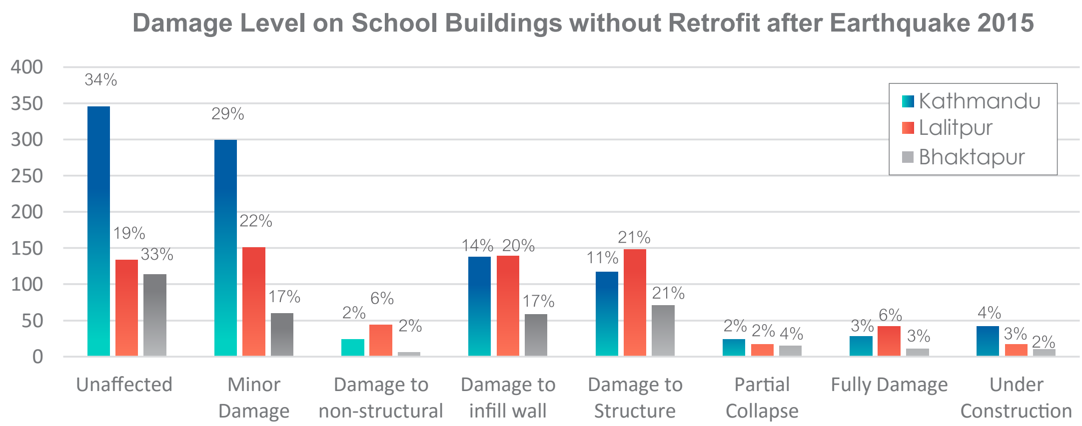


Figure 7: *Damage state of non- retrofittted blocks of school buildings in Kathmandu valley (Source: SIDA 2016)*

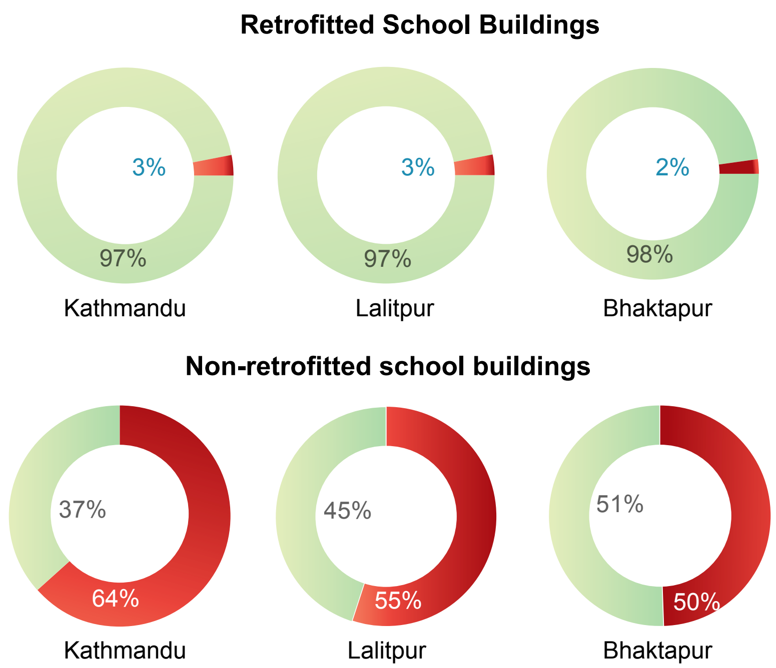


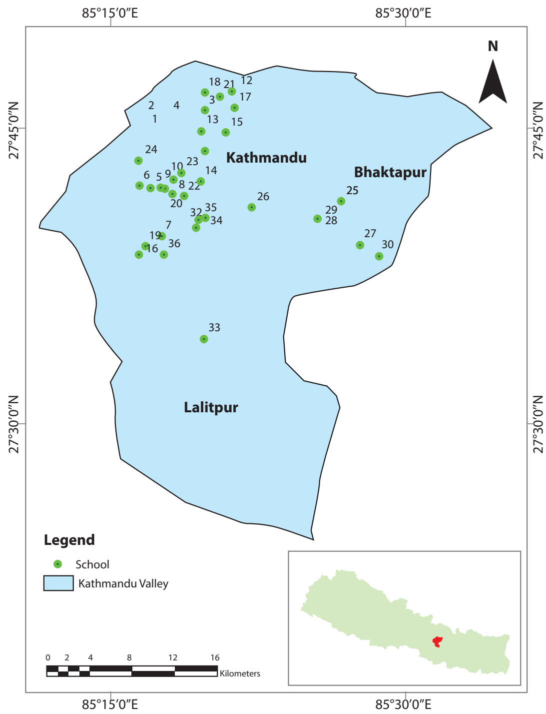
Figure 8: *Tag color in retrofitted and non-retrofitted school buildings. Green color represents that immediate occupancy can be undertaken and Red represnts that building is vulnerable for immediate use.*

As part of the study undertaken by AIT, detailed study of retrofitted school buildings was carried out after the earthquake. We found that the following two methods have been broadly used as the retrofitting methods for the school buildings in Nepal.

- Reinforced concrete (RC) jacket
- Splint and bandage

Site Visit & Assessment

The AITS team and researchers visited schools in the aftermath of the earthquake for an impact assessment. We selected both retrofitted and non-retrofitted schools inside the Kathmandu valley to compare the performance after recent Gorkha 2015 earthquake. The school lists were facilitated by NSET and we visually assessed each school and obtained the information from the management committee.



Selection of School Buildings

- Facilitated by NSET
- 2000-2014 retrofitted schools
- Constructed from early to late 90s

Kathmandu Bhaktapur Lalipur

- Selection was made without knowing the damage level

Primilinary Investigations

- In-site observation for a full day.

Figure 9: *Figure Location of selected school buildings inside Kathmandu valley (both retrofitted and non-retrofitted)*

Key Findings

A total of 37 school buildings were assessed around different districts inside the Kathmandu valley. Among the surveyed school buildings, schools were further categorized into different blocks in the same compound. The survey shows 29 retrofitted blocks and 18 are non-retrofitted blocks.

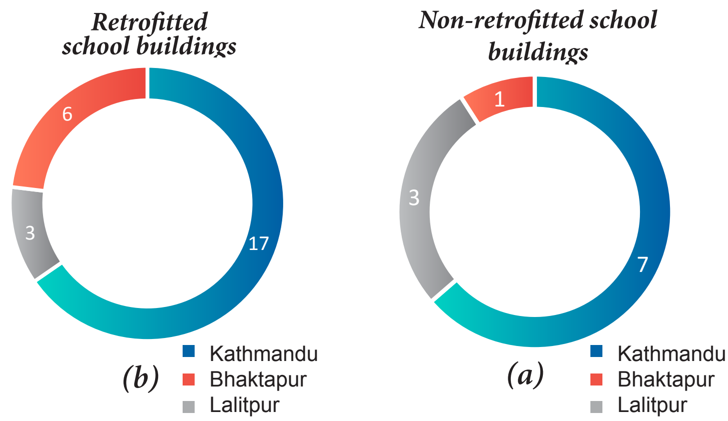


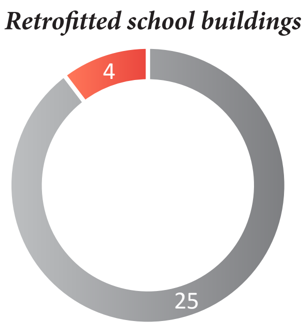
Figure 10: *Summary for retrofitted and non-retrofitted school buildings in three districts inside Kathmandu valley*

Retrofitted school buildings performed satisfactorily well with minor hairline cracking to almost no damage. In some locations of Kathmandu valley, concentrated effects of the earthquake were seen, where retrofitted school buildings were able to withstand the earthquake effects compared to surrounding non-retrofitted school buildings and other residential buildings. Three retrofitted school buildings show minor damage (cracks in infill wall) but the overall performance of the school buildings was enhanced by concrete jacket and splint-bandage.

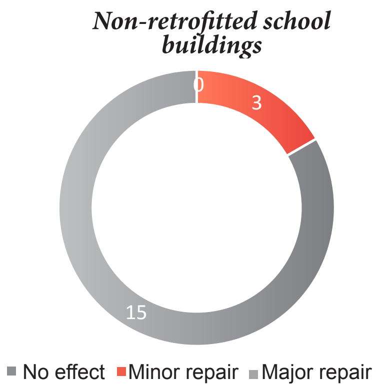
Figure 11: *A school building in Kathmandu shows different response. The building originally was load bearing masonry retrofitted with concrete jacket was undamaged and was aavailable to continue classes after earthquake.*

Non-retrofitted school buildings performed poorly compared to retrofitted school buildings. Most of the school buildings experienced minor to severe damage in the earthquake. The damage in non-retrofitted schools was notonly limited to concentrated areas of Kathmandu valley but also in majority of the surveyed locations. Some of the school buildings were completely collapsed after the shaking. The damage in non-retrofitted schools are extended to URM buildings to RCC framed buildings. In the concentrated areas where stronger ground shaking was seen, the school buildings performed poorly. The major problem was low strength brittle constructions lacking minimum seismic detailing which makes it more vulnerable to strong ground shaking.

Figure12: *A school building in Kathmandu shows different response. The building at the back, load bearing masonry was moderately damaged in the earthquake and the building at the left, load bearing masonry, retrofitted with concrete jacket was undamaged and was available immediately for restarting classes after earthquake.*



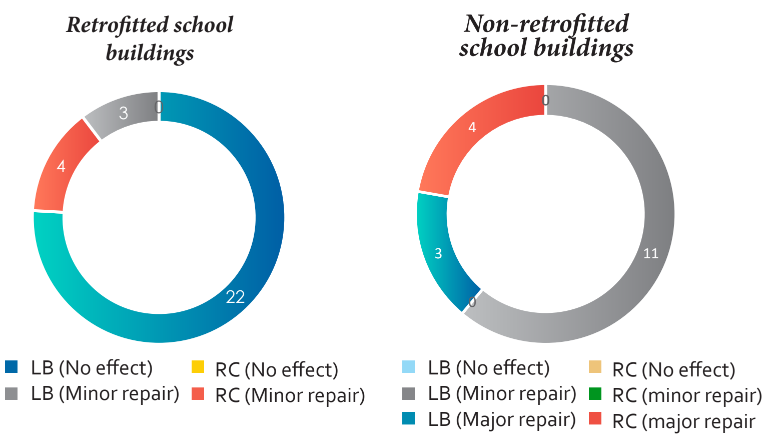
(a)



(b)

Figure13: *(a) Summary of the performance of retrofitted school buildings. Almost all retrofitted schools perform better in the earthquake (b) Summary of the performance of non-retrofitted school buildings showing majority of school buildings were affected in the earthquake.*

Majority of the buildings assessed were old constructions i.e. load bearing unreinforced masonry buildings. Majority of the buildings lacked seismic detailing and were retrofitted for possible earthquake hazard. The survey reflects that the unreinforced old masonry buildings can also be upgraded to withstand the possible seismic hazard in the future.



(a) *(b)*

Figure14: *(a) Summary of performance based on building typology (retrofitted school buildings) (b) Summary of performance based on building typology (non-retrofitted school buildings)*

Further classifications of surveyed buildings are provided in Appendix B.

Conclusions & Recommendations

The devastating impact of the earthquake provides an opportunity to evaluate the construction techniques and utilize safe and earthquake resistant methods and assess the performance of reinforced concrete jacket and splint-bandage retrofit applied to masonry school buildings in recent earthquake. Seismic performance of this retrofitting technique was assessed based on comparison made between retrofitted and non-retrofitted school buildings inside Kathmandu valley.

Overall, all the retrofitted school buildings surveyed in Kathmandu valley performed well during the earthquake. These buildings demonstrated enhanced performance in the concentrated areas in Kathmandu valley whereby other nearby buildings suffered significant damage or collapse. The retrofitting helps to maintain the integrity of the low strength brittle structures vulnerable in the earthquake. Retrofitted school buildings perform satisfactorily well with minor hairline cracking to no damage in the earthquake. Very few retrofitted school buildings experienced minor cracking in the walls.

Retrofitted buildings

- All the surveyed buildings performed well in the earthquake without minor damage.
- Retrofitting successfully helps to maintain the integrity of low strength and brittle vulnerable masonry school buildings.

Non-retrofitted buildings

- Post-earthquake surveys after the recent earthquake have shown poor performance of non-retrofitted school buildings which are often vulnerable
- Poor construction practice, deterioration of materials, lack of seismic resistant design and some localized effects cause more damage.

The visual assessment of the non-retrofitted school buildings provides different vulnerability factors that cause substantial damage in the school buildings. Deterioration of materials due to aging, weak load path due to flexible diaphragm of the school building, insufficient or lack of reinforcement in critical regions like openings and intersection of cross walls, insufficient anchorage for masonry walls, weak and soft story due to larger size of the rooms, loss of cohesion between masonry unit and mortar are some of the reason behind collapse.

The performance of the unreinforced school buildings is consistent with expected failures cases (out-of-plane wall failure, in plane shear cracking, roof-floor separations, joint failure in the intersection of the walls) of these type of buildings in the past earthquakes.

The damage assessment survey (SIDA 2016) of World Bank also reflects, performance of vulnerable school buildings were enhanced by retrofitting. Thus retrofitting may be a better solution for strengthening the vulnerable school buildings for possible disaster in the future.

- Despite being made of a weaker building material (low strength brittle structures), the retrofit proved to be successful.
- Retrofitting can be the better solution to make existing masonry school buildings earthquake resistant, rather demolishing them.
- The actual behavior of the buildings in recent earthquake were obtained through visual inspection.

Many of the school buildings in Nepal are still vulnerable to earthquakes of medium and strong intensity. The schools that survived in April and May 2015 earthquakes are still not safe as per present requirements of seismic resistant buildings. Thus the buildings should be repaired, retrofitted or demolished based upon the assessment. Decision makers regarding public infrastructures in Nepal can take the following steps to provide safe spaces for all.

1. Risk and assessment

- Determining the existing schools in need of urgent intervention.
- Identify the vulnerabilities in the buildings (structural and non-structural components).
- Determine either retrofit or reconstruction.
- Formulate proper retrofitting technique to strengthen the building.

2. Building codes and retrofitting guidelines

- Building codes serve as a minimum requirement that a building must ensure the safety of the occupants. Prioritization should be focused on appropriate building codes to meet the demands for safer and disaster resilient school for new construction and enhancement of existing unsafe schools to specified performance level.
- All the building codes may or may not specify the retrofitting techniques and guide lines. Thus a guidelines containing detail description of techniques used for retrofitting of unsafe buildings in disaster is a must for any country.

3. Prepare retrofitting plan:

- Preparation of appropriate design criteria based upon the, retrofitting technique, availability and suitability of resources, cost and other constraints.
- Prepare detail design (both architectural and structural) based on the performance objectives, assessment results and building codes.
- Preparation of construction documents and inspection guidelines.
- Preparation of work plans.
- Ensure the design meets the performance objectives and building code requirements for safer school.

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Appendix A

Reinforced concrete (RC) jackets on both sides:

Reinforced concrete jacketing is a traditional and well established strengthening technique that enhances the structural performance and serves as a viable option for engineers in seismic active areas. Utilizing RC jackets can increase the stiffness, strength and overall structural performance enhancement are the qualities of concrete jacketing. This quality of RC jackets for its frequent use in the retrofitting of structural components as well as non-structural components. This method is feasible for both brick masonry and stone masonry walls. The covering of the outer surface of the wall is termed as jacketing. This retrofit technique is used due to its technical and economic feasibility along with the availability of local builders and masons. The technique improves the overall performance of the structure and ensure a level of life safety (Shiwaku et al., 2007). The process covers concrete layer on one side or both of the masonry wall. This can be also termed as reinforced concrete coatings, overlay, cladding or mesh (Sergey Churilov & Elena Dumova-Jovanoska, 2012).

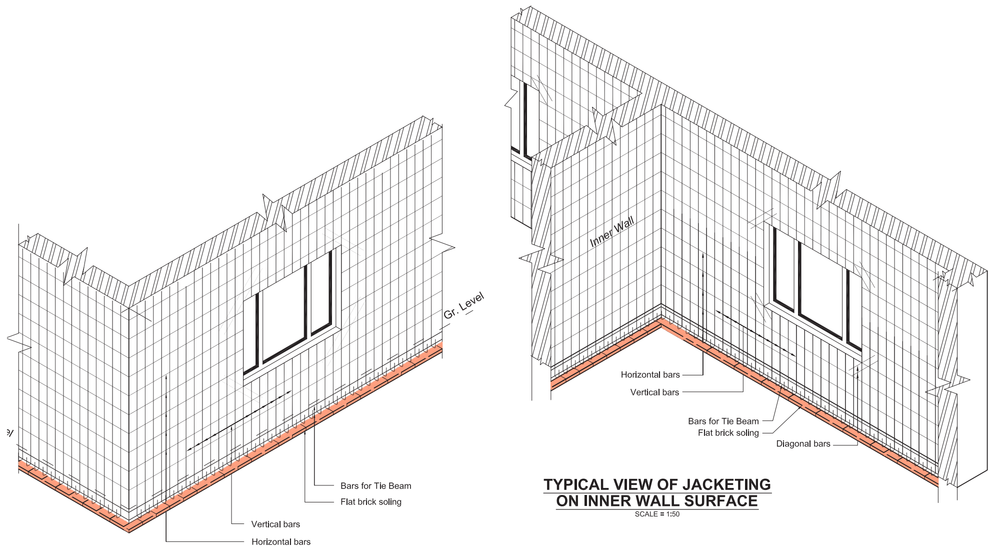


Figure 15: *Arrangement of reinforcement in the outer & inner wall before application of concrete layer on both sides of the wall (Source: NSET 2013)*

All the retrofitting work on school buildings are done in accordance with the Nepal Building Code (NBC) guidelines, current best practice, building regulations, project specifications, Indian standard codes, and materials deemed appropriate for their intended use. The concrete used is of 20 MPa, 28 days compressive strength and TMT reinforcing steel of 500 MPa. A certain portion of the earth surface is excavated for the horizontal tie beams before applying the jacket and concreting is carried out in the tie beam above the flat brick soling as shown in the figure below.

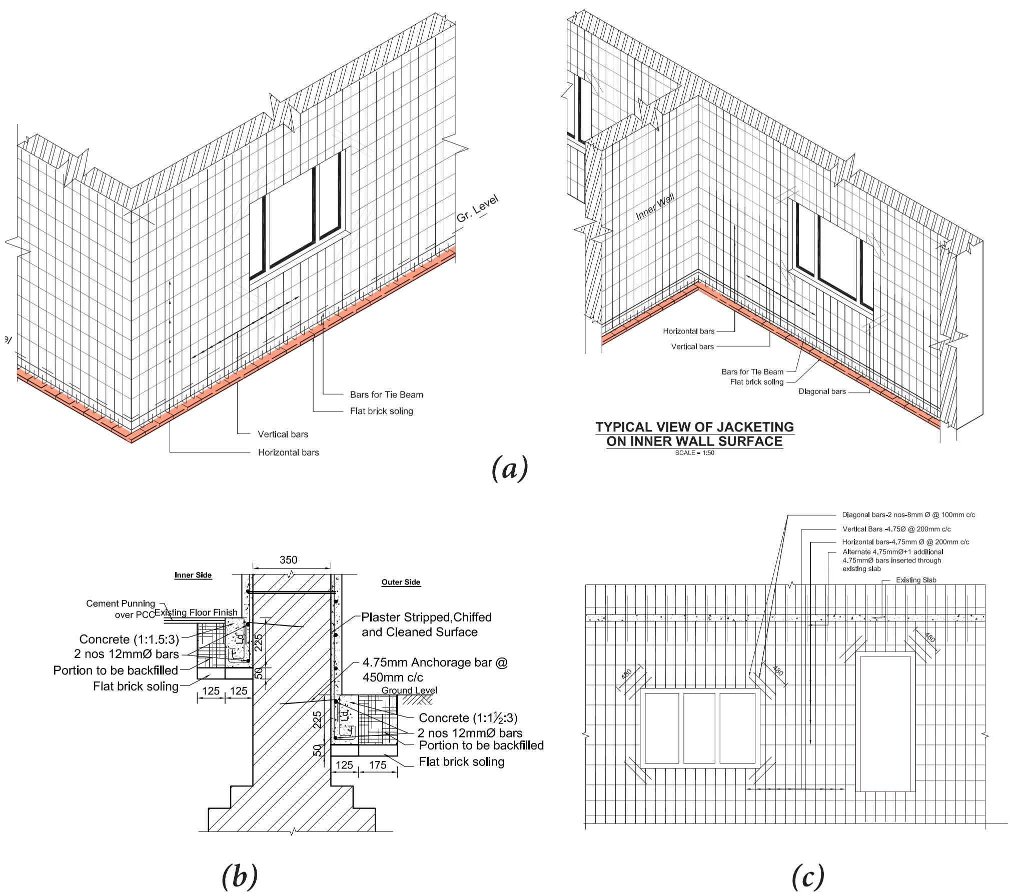
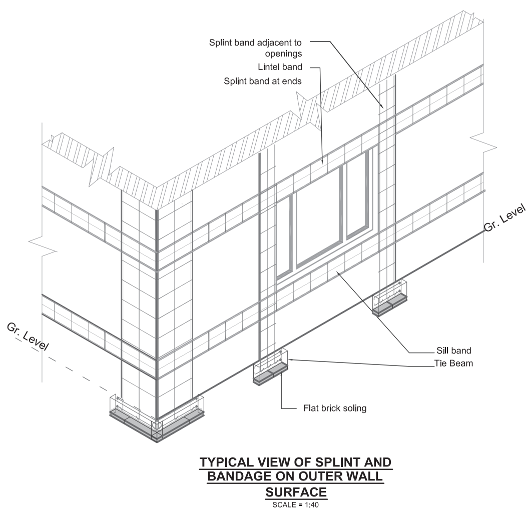


Figure 16: *(a) Arrangement of reinforcement in the outer & inner wall before application of concrete layer on both sides of the wall (b) Preparation of foundation before arranging the reinforcement (c) Extra reinforcement provided near the openings of the wall (Source: NSET)*

The horizontal bars 4.75mm diameter @ 200mm c/c in longitudinal direction and vertical bars 4.75mm diameter @ 200mm c/c for the wall in transverse direction are arranged above the first layer of concreting and the second layer of concrete is provided along with cement-mortar plaster. The two layer of the jackets are interconnected each other with GI wire as shown in the figure. The vertical bars are anchored in the roof slab of the buildings. Every third bar 4.75mm + one additional 8mm bar are inserted through the existing floor slab. Additional reinforcement is also provided in the critical corners of the openings (2nos of 8mm dia. bar, 100mm c/c of 480mm length) as shown in figure 7.

Structural details for splint-bandage on both sides:

The splint and bandage is considered as the economical version of reinforced concrete jacket where the reinforcing bars are provided at the critical locations. Splints are the vertical elements provided on the wall and bandages are the horizontal components on the wall. The goal of splint is to increase the tensile strength of the masonry wall in the vertical directions and prevent the wall from dislodging due to the cracking. The steel provided will prevent the masonry wall from the diagonal cracks or restrain the crack from widening. The bandages provided horizontal helps to integrate the walls together. The splints and bandages are provided in both layers of the wall, lintels of the openings, below the roof level and the corners of the buildings as shown in figure (JK Bothara et al., 2004).



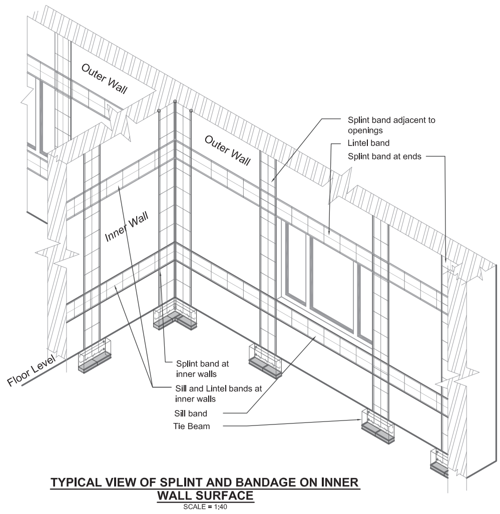


Figure 17: *Arrangement of reinforcement in the outer & inner wall before application of concrete on both sides of the wall (Source: NSET 2014)*

The horizontal bars for bandages is of 8mm diameter @ 150mm c/c with 4.75mm@150mm c/c stirrups and vertical bars for splints is of 8mm diameter @ 150mm c/c with 4.75mm@150mm c/c stirrups. The bars are arranged above the first layer of micro concrete and the second layer of micro concreting is provided along with cement-mortar plaster. The splints in inner and outer wall are interconnected each other with GI wire as shown in figure.

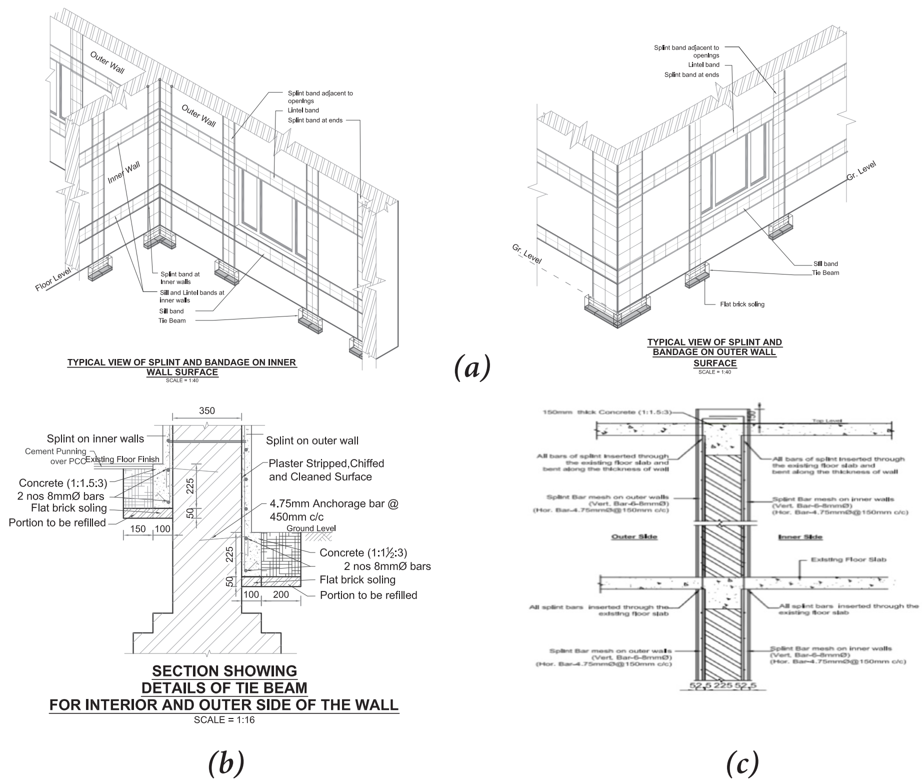


Figure18: *(a) Arrangement of reinforcement in the outer & inner wall before application of splint-bandages on both sides of the wall (b) Preparation of foundation before arranging the reinforcement (c) cross section detail for the splint and bandage (Source: NSET)*

Structural details for concrete jacket on outer wall and splint-bandage on inner wall:

In many school buildings, retrofitting has been carried out by the application of concrete jacket on outer wall and splint-bandage in inner wall in accordance to the vulnerability assessment of existing building as shown in figure. This is also an economical form of concrete jacketing. All the procedures for retrofitting are same as described earlier.

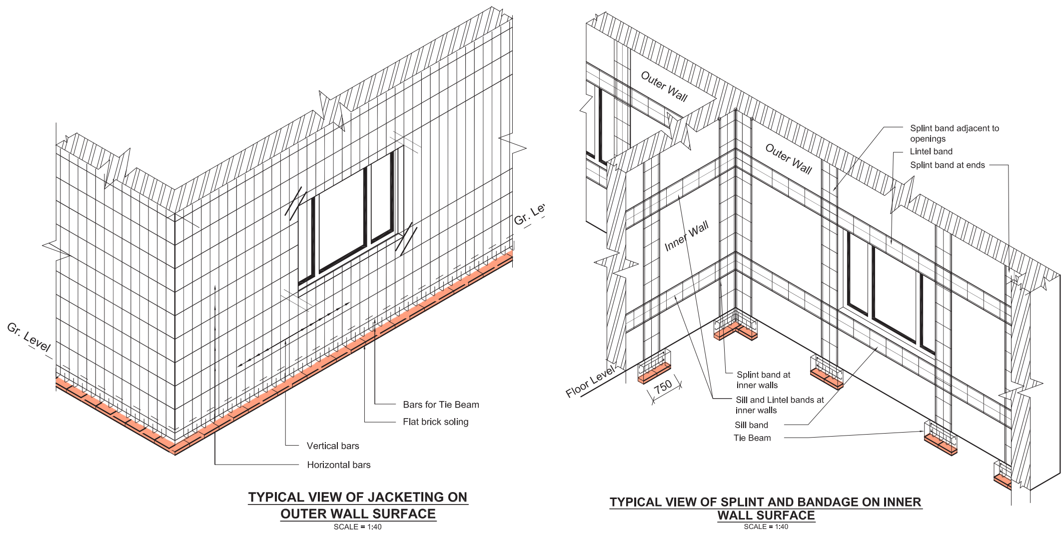


Figure 19: *Arrangement of reinforcement in the outer & inner wall before application of concrete jacket on outer wall and splint-bandages on inner wall (Source: NSET 2013)*

The horizontal bars 4.75mm diameter @ 200mm c/c in longitudinal direction and vertical bars 4.75mm diameter @ 200mm c/c for the wall in transverse direction are arranged above the first layer of micro concreting and the second layer of micro concrete is provided along with cement-mortar plaster. The horizontal bars for bandages is of 8mm diameter @ 150mm c/c with 4.75mm@150mm c/c stirrups and vertical bars for splints is of 8mm diameter @ 150mm c/c with 4.75mm@150mm c/c stirrups. The bars are arranged above the first layer of micro concrete and the second layer of micro concreting is provided along with cement-mortar plaster. The splint-bandage in inner and concrete jacket in outer wall are interconnected each other with GI wire.

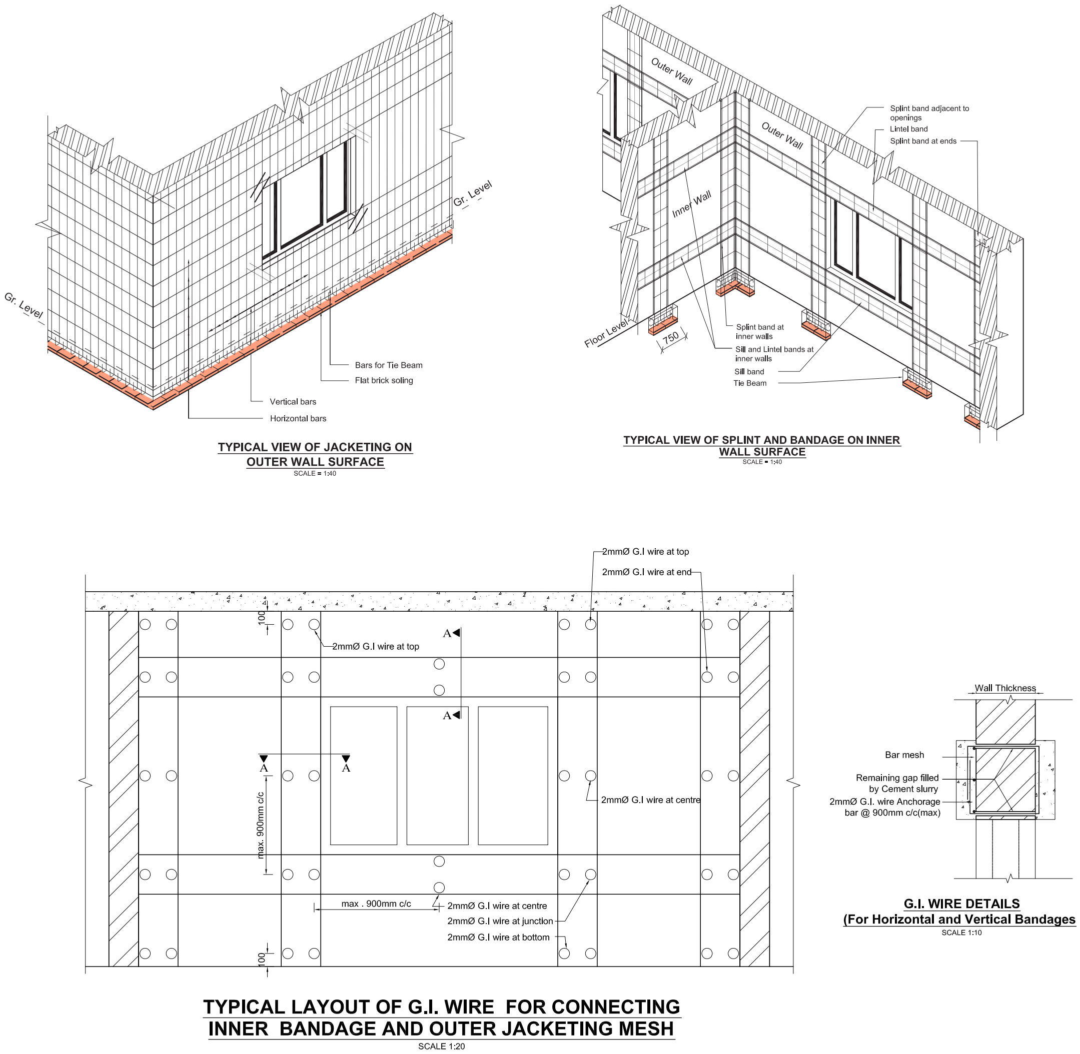


Figure 20: *Arrangement of reinforcement in the outer & inner wall before application of concrete jacket on outer wall and splint-bandage in inner wall.*

Appendix B

Classification of surveyed schools based on structural system, number of stories, units & binding materials:

Depending upon the structural system used in the buildings, the school buildings are divided according to structural typologies into two main systems: Load bearing masonry (LB) and reinforced concrete framed (RC) systems. 26 blocks are retrofitted load bearing and 11 blocks are non-retrofitted load bearing blocks and 3 blocks are retrofitted framed buildings and 7 blocks are non-retrofitted framed blocks.

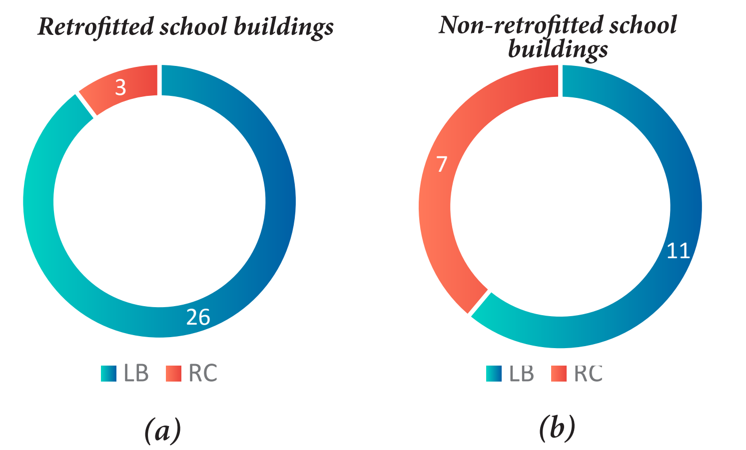


***Figure21:** Summary for retrofitted and non-retrofitted school buildings in three districts inside Kathmandu valley divided by structural typology*

Further, the school buildings were divided based upon the number of stories for both retrofitted and non-retrofitted school buildings as shown in figure.

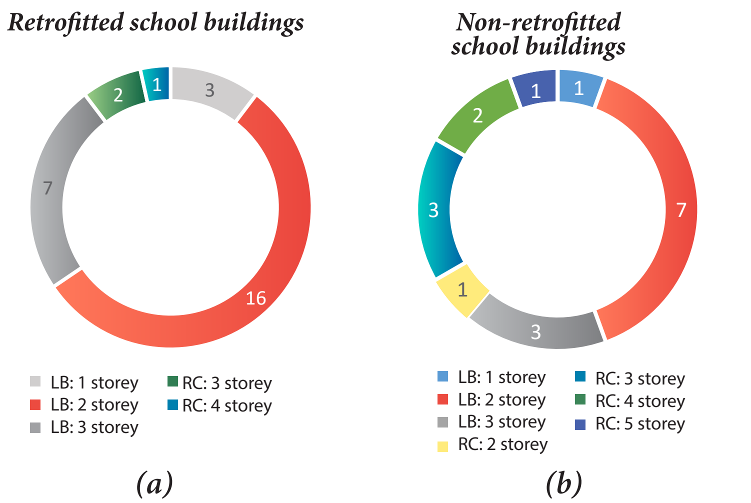


***Figure22:** Summary for retrofitted and non-retrofitted school buildings in three districts inside Kathmandu valley*

The surveyed schools were divided based upon units and binding materials used during construction. Depending upon the materials used, the school buildings were divided into three groups i.e. brick with mud mortar, brick with cement mortar and mixed (mud mortar and cement mortar in different story level).

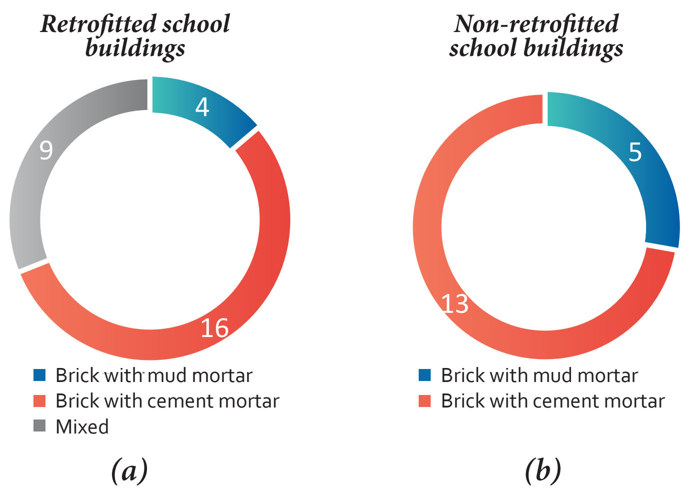


Figure 23: *Summary for retrofitted and non-retrofitted school buildings based upon joint materials in three districts inside Kathmandu valley*

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