buildings

MDPI

Case Report

An Analytical Study on the Damage to School Buildings by the 2015 Nepal Earthquake and Damage Level-Based Reconstruction Experience

Youb Raj Paudyal [1] and Netra Prakash Bhandary [2,*]

[1] Central Level Project Implementation Unit, Ministry of Education, Science and Technology, Kathmandu 44600, Nepal; youbrajpaudyal@gmail.com
[2] Department of Environmental Design, Faculty of Collaborative Regional Innovation, Ehime University, Matsuyama 790-8577, Japan
* Correspondence: netra@ehime-u.ac.jp; Tel.: +81-89-927-8566

Abstract: The 2015 Nepal Earthquake (Mw7.8) affected more than 9000 schools in the country. Damage distribution in the 14 most-affected administrative districts shows that the construction practices were an important determent for the level of damage extended. The use of improper construction materials, lack of construction supervision, and non-compliance with the existing building codes during design and construction probably contributed to severe damage to most of the school buildings. Based on the damage analysis data and experience of the rebuilding process after the 2015 Nepal Earthquake, this paper highlights the steps to be considered during a rebuilding plan for school buildings after an earthquake disaster. Preliminary damage assessment results show that in the most-affected districts, about 86% of schools (locations) were affected by the earthquake and about one million students were out of their schools for a long time. The damage survey data indicate that about 30% of classrooms collapsed, about 13% of classrooms sustained major damage, and about 17% of classrooms sustained minor damage within the most-affected 14 districts. This damage report is largely based on the secondary data provided by the concerned government authorities. Such evidence of loss and damage in earthquake disasters provides an opportunity to learn lessons for future preparedness and to encounter disaster challenges. This work shares an experience on the rebuilding process of damaged schools and classrooms. It is expected that the experience reported in this paper will help in better planning of the seismic safety of school buildings in Nepal as well as in other similar seismically active regions. Most papers related to the 2015 Nepal Earthquake focus on overall building damage, but this paper addresses the issues of school buildings. As a case report, this paper probably lacks scientific originality, but the presentation of the damage data and the rebuilding process are the original work of the authors.

Keywords: 2015 Nepal Earthquake; school buildings; damage assessment; rebuilding program

check for updates

Citation: Paudyal, Y.R.; Bhandary, N.P. An Analytical Study on the Damage to School Buildings by the 2015 Nepal Earthquake and Damage Level-Based Reconstruction Experience. *Buildings* **2024**, *14*, 451. https://doi.org/10.3390/buildings14020451

Academic Editor: Ehsan Noroozinejad Farsangi

Received: 15 October 2023
Revised: 29 January 2024
Accepted: 30 January 2024
Published: 6 February 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The 2015 Nepal Earthquake (Mw7.8), with its epicenter about 80 km northwest of the capital Kathmandu produced strong shakings in the central part of the country and caused massive damages. Out of the total 75 administrative districts in the country, 14 (as indicated by 'Severely hit' and 'Crisis hit' in Figure 1) were heavily affected. The quake killed about 9000 people and destroyed about 600,000 houses and about 9000 school buildings [1]. The total economic loss in the education sector including the school infrastructures and physical assets was estimated at NPR 31.3 billion (Nepalese Rupee) [2], which is equivalent to about USD 300 million. More than 80% of this loss in the education sector, particularly in damage to public-school buildings, occurred in the 14 most-affected districts towards the east of the epicenter (refer to Figure 1).

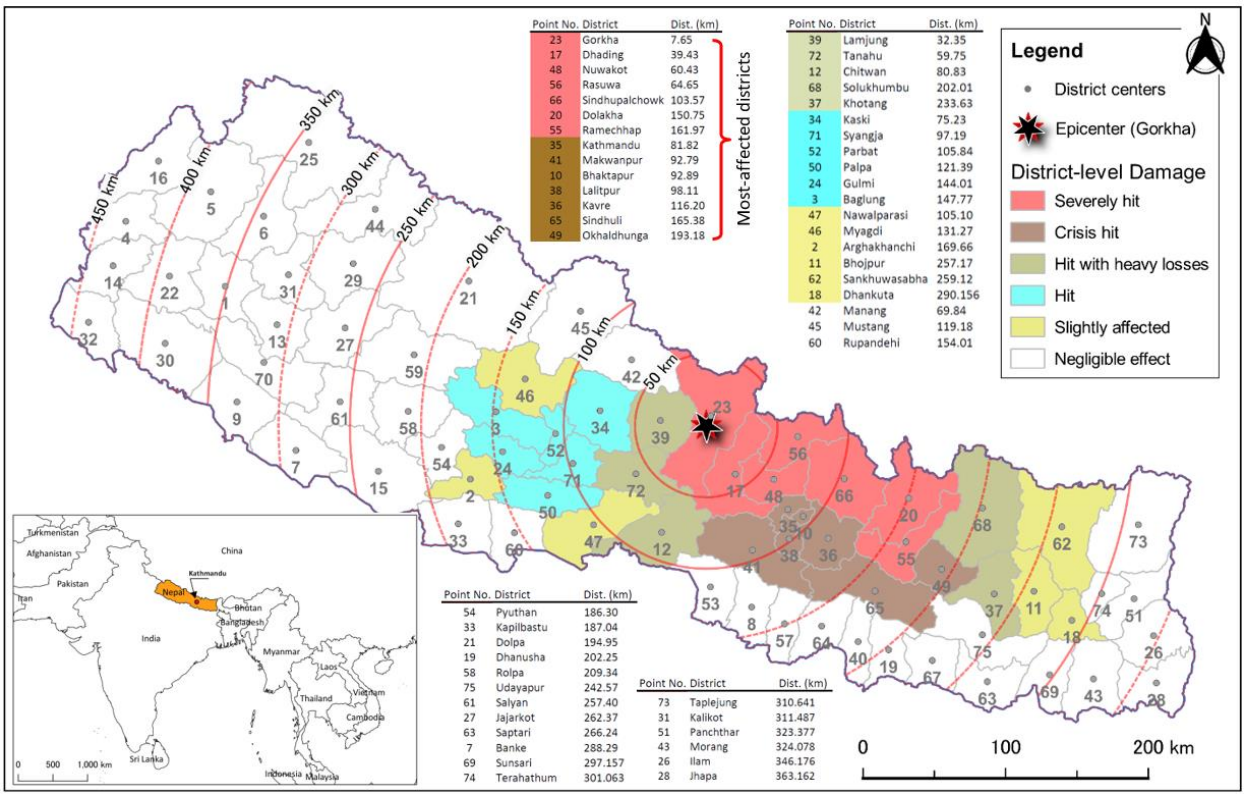


Figure 1. Administrative districts affected by the 2015 Gorkha Earthquake in Nepal including the most affected 14 districts (PDNA 2015).

There has been a large amount of research work conducted so far in relation to seismic school safety and seismic damage to school buildings (e.g., Fajfar and Gaspersic [3], Di Ludovico et al. [4], Ruggieri et al. [5], Giordano et al. [6], Ruggieri et al. [7], etc.). Among the high seismic risk regions, the public-school buildings in Nepal are particularly susceptible to seismic damage because of poor construction materials and method. Especially in the remote mountainous areas of Nepal, the building construction practice still largely depends on locally available materials such as rounded stones, mud, and raw timber and locally available less-trained masons. Compared to urban and motorable road-connected areas, where the building construction practice mostly relies on reinforced concrete and cement-mortared brick masonry walls, primarily because of cheaper construction option and material transportation issues, most private houses and school buildings in the remote mountainous areas are seismically unsafe. Even in heavily urbanized areas such as the Kathmandu valley, a study conducted in 1998 by the National Society for Earthquake Technology (NSET) revealed that about 15% of the school buildings were structurally dilapidated and needed demolition and rebuilding [8]. Moreover, as high as 60% of the public-school buildings in the valley were found to be vulnerable to seismic damage [9]. The NSET study [8] also highlighted a compelling need of developing and implementing an effective, integrated, and ground-real strategy for radically improving the seismic safety of schools all over the country. Despite a higher risk of earthquake disasters in Nepal [10–12], school building construction practice has largely ignored the issues of structural safety, especially in terms of structural design and construction. Even for the reinforced concrete buildings, the seismic safety issues are questionable because of non-compliance to the seismic design code and construction norms. In relation to the seismic safety, the need of compliance to building design codes and construction norms, and the seismic damage scenario of the reinforced concrete buildings for various purposes, the existing literature highlights and brings forward many important issues that will further help improve the seismic safety and resistibility of the reinforced concrete buildings, e.g., [13–17].

The high vulnerability level of school buildings was well evidenced in the 2015 earthquake, which destroyed thirty-six thousand classrooms in total, but fortunately during off-school hours. This extent of damage to the schools virtually affected about one million children, who were not able to properly attend their schools for several months [2].

According to the National Reconstruction Authority, constituted by the Government of Nepal after the earthquake to look after and implement all recovery and reconstruction work strategy, the total number of schools to be reconstructed was more than 7500 in 32 of the 53 affected districts [18]. The school reconstruction plan mainly involved the School Management Committee (SMC) through government funding, which took over nearly 80% of the total reconstruction work. Of the rest 20% rebuilding work, International Non-government Organizations (INGOs) and Non-governmental Organizations (NGOs) took over 10%, and the development partners took over 10% work directly through the contractors (Figure 2a). The status of the progress made in the school reconstruction plan as of August 2021 is shown in Figure 2b: 88% of the damaged schools have already been reconstructed while 12% are still under construction.

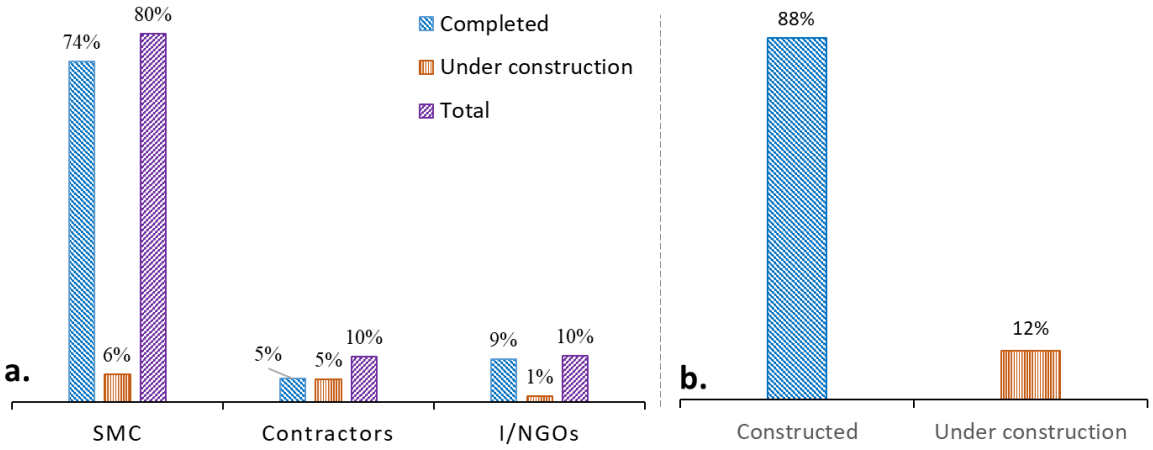


Figure 2. Status of school earthquake reconstruction in the 14 most-affected districts: (**a**) status of school reconstruction by different parties, (**b**) overall status of school reconstruction (as of August 2021) (SMC: School Management Committee; I/NGOs: International and Domestic Non-governmental Organizations).

Not only the school reconstruction plan, but the whole earthquake reconstruction program was also expected to be completed within a year or so as of August 2021. The reconstruction plan and experience, especially in rebuilding the schools in this paper's context may be an important reference for any future earthquake school rebuilding programs in other parts of the country as well as in other similar earthquake-prone countries. So, the objectives of this damage data analysis-based study are as follows: (1) spatial interpretation of the school building damage distribution; (2) building material-based damage extent analysis; (3) damage scenario-based rebuilding experience sharing as a guideline to prepare for any future earthquake disasters in the country, as introduced in the following section, as well as in similar high seismic risk areas of the world.

2. Materials and Methods

2.1. Damage Survey and Data Collection

The school damage-related data in the 53 affected districts were collected through the district-level offices of the Department of Education of the Government of Nepal (as also mentioned by Giordano et al. [6]). The damage data were recorded on a rapid damage assessment form (Figure 3), which was developed after wide consultations with different stakeholders including the Department of Education (DOE), the Department of Urban Development, and Building Construction (DUDBC), the United Nations Children's Fund (UNICEF), Save the Children (SC), and so on with the support of engineers, sub-

engineers, resource persons, school supervisors, and schoolteachers. Also, during the damage survey, the Educational Management Information System (EMIS) code of each school was extracted from the Flash I Report 2015 of the Department of Education, and it was used as an identification number for analyzing the data [19]. School buildings were classified according to the material and structure types used in construction, such as reinforced concrete (RC), steel frame, adobe, bamboo, stone masonry in mud mortar, stone masonry in cement–sand mortar, brick masonry in mud mortar, brick masonry in cement–sand mortar, etc.

Rapid Damage (Technical) Assessment of Schools

1. General					
1.1. Inspector/Team Leader Name:			1.2. Date:		
2. School Description					
2.1. Name of school:			2.2. EMIS school code:		
2.3. Address (VDC/MP):					
2.4. Type of school: ☐ Community ☐ Institutional ☐ Traditional					
2.5. Head teacher's name:			2.6. Contact No.:		
Deaths from earthquake (if none, put '0') 2.7. Students: _____ 2.8. Teachers: _____			2.9. No. of toilets currently usable: _____ 2.10. No. of toilets damaged by earthquake: ____ 2.11. Water supply available? ☐ Yes ☐ No		
2.12. Is land area available for a temporary structure? ☐ Yes ☐ No			2.13. Is the compound wall damaged? ☐ Yes ☐ No		
2.14. Estimated total cost of damage/loss in NRs. (if any):					
3. Building Block Description					
3.1. Which block? (assign a number)		3.2. No. of stories:		3.3. Year constructed:	
3.4. Total No. of rooms:	3.5. No. of rooms used as classrooms:		3.6. No. of classrooms collapsed:		
3.7. Building constructed by (select only ONE): ☐ EAARP (Earthquake project) ☐ BPEP ☐ EFA ☐ JICA ☐ Community ☐ Other (specify):					
3.8. Type of building (select only ONE): ☐ Load bearing ☐ Steel frame ☐ RC frame ☐ Other (specify):					
3.9. Type of wall construction (select only ONE): ☐ Adobe ☐ Bamboo ☐ Stone in mud ☐ Stone in cement ☐ Stone in cement ☐ Brick in mud ☐ Brick in cement ☐ Other (specify):					
3.10. Type of floor (select only ONE): ☐ Flexible ☐ Rigid			3.11. Type of roof: ☐ Flexible ☐ Rigid		
3.12. Is this building completely collapsed? (If yes, go to section 4 "Non-structural items") ☐ Yes ☐ No					
3.13. Is this building partially collapsed or moved off its foundation? ☐ Yes ☐ No					
Observed condition of amount of damage (select only ONE per category)	No damage	Minor	Moderate	Severe	Not applicable
3.14. Building or any story out of plum	☐	☐	☐	☐	☐
3.15. Damage to column, beams or other structural members	☐	☐	☐	☐	☐
3.16. Cracking of walls and corners or other sign of distress present	☐	☐	☐	☐	☐
3.17. Parapet, water tank, or other falling hazards	☐	☐	☐	☐	☐
3.18. Large fissures in ground, massive ground movement or slope displacement present	☐	☐	☐	☐	☐
3.19. Other hazard (e.g., Tree, Power line, etc.) Specify:	☐	☐	☐	☐	☐
3.20. Estimated overall building damage (select only ONE) ☐ 0% ☐ 1–25% ☐ 26–50% ☐ 51–75% ☐ 76–99%					
4. Non-Structural Items					
Indicate what percentage of the following items IN THIS BUILDING BLOCK are still usable: 4.1. Desk-bench: % 4.2. Table: % 4.3. Chairs: %					

Figure 3. Rapid damage assessment form developed after the 2015 Gorkha Earthquake.

To estimate the building damage grade as well as classroom damage level, the European Macroseismic Scale 1998, Vol. 15 [20], as presented in Table 1, was referred to. Based on the collected data, the damage grades were judged in terms of collapse (i.e., Grade 5), major damage (Grade 2, Grade 3, and Grade 4), minor damage (Grade 1), and no damage.

Some typical damage types of the school buildings in the survey area are shown in the photographs of Figure 4. These damage types also indicate that most school buildings either suffered total collapse or partial damage due to brick or stone masonry wall collapse.

Table 1. Damage grade based on the European Macroseismic Scale 1998 (EMS-98).

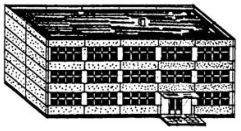
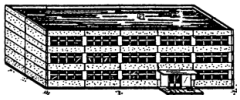
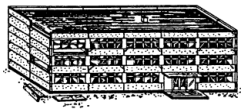
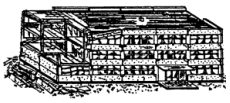
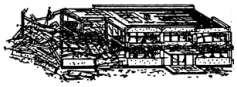
Damage Grade	Load Bearing Masonry Buildings	Reinforced Concrete (RC) Buildings
Grade 1 (G-1)	• Negligible to slight damage (no structural damage, slight non-structural damage)  • Hair-line cracks in very few walls • Fall of small pieces of plaster only • Fall of loose stones from upper parts of buildings in very few cases	• Negligible to slight damage (no structural damage, slight non-structural damage)  • Hair-line cracks in plaster over frame members or in walls at the base • Fine cracks in partitions and infills
Grade 2 (G-2)	• Moderate damage (slight structural damage, moderate non-structural damage) • Cracks in many walls  • Fall of fairly large pieces of plaster • Partial collapse of chimneys	• Moderate damage (slight structural damage, moderate non-structural damage)  • Cracks in columns and beams of frames and in structural walls • Cracks in partition and infill walls • Fall of brittle cladding and plaster • Falling mortar from the joints of wall panels
Grade 3 (G-3)	• Substantial to heavy damage (moderate structural damage, heavy non-structural damage)  • Large and extensive cracks in most walls • Roof tiles detach, chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls)	• Substantial to heavy damage (moderate structural damage, heavy non-structural damage)  • Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spilling of concrete cover, buckling of reinforced rods • Large cracks in partition and infill walls, failure of individual infill panels
Grade 4 (G-4)	• Very heavy damage (heavy structural damage, very heavy non-structural damage)  • Serious failure of walls; partial structural failure of roofs and floors	• Very heavy damage (heavy structural damage, very heavy non-structural damage)  • Large cracks in structural elements with compression failure of concrete and fracture of rears; tilting of columns. Collapse of a few columns or of a single upper floor
Grade 5 (G-5)	• Destruction (very heavy structural damage) • Total or near total collapse 	• Destruction (very heavy structural damage)  • Collapse of ground floor or parts (e.g., wings) of buildings



Figure 4. Typical examples of damage of school buildings during the 2015 Gorkha Earthquake: (**a**) reinforced concrete (RC), (**b**) steel frame with masonry walls, and (**c**) stone masonry with mud mortar.

2.2. Rebuilding Plan

The overall earthquake reconstruction plan was prepared and implemented by a newly constituted government agency, the National Reconstruction Authority (NRA), as of 25 December 2015. To implement the school rebuilding plan, however, a different government agency, the Central Level Project Implementation Unit (CLPIU), under the Ministry of Education was setup, to engage basically in recovery and reconstruction of damaged schools through necessary coordination, communication, and collaboration with all relevant government agencies, international and national non-government organizations (INGOs and NGOs), and development partners. In the local levels, District Level Project Implementation Units (DLPIU) were setup under CLPIU to focus on implementing and monitoring the recovery and reconstruction work within their territories.

The 14 most-affected districts (i.e., Gorkha, Dhading, Nuwakot, Rasuwa, Sindhupalchok, Dolakha, Ramechhap, Kathmandu, Makwanpur, Bhaktapur, Lalitpur, Kavre, Sindhuli, and Okhaldhunga as indicated in Figure 1) were prioritized for emergency response through the implementation of the recovery and reconstruction program. Towards building the school reconstruction plan in the most-affected districts, the Department of Education constituted a committee for overall damage data management and reconstruction plan, including collection, compilation, and dissemination of the data to the concerned agencies. A total of 14 under secretaries of the Department of Education were deputed as the focal persons for collecting the damage data from the 14 districts and for supporting the committee in the data compilation as well as to implement the rebuilding program.

3. Results, Discussion, and Implication

3.1. Nation-Wide School Building Damage Scenario

According to the data collected and availed by the Department of Education, the 2015 Nepal Earthquake affected the school facilities of 53 out of the 75 administrative districts in Nepal. The status of loss and damage in the 53 districts is graphically presented in Figures 5–7. As indicated in Figure 5, about 44% of 21,117 schools were directly or indirectly affected by the earthquake. Likewise, as in Figure 6, of about 231,000 total number of classrooms in the 53 districts, nearly 10% (i.e., 22,371) classrooms completely collapsed, a little more than 6% (i.e., 13,818) of classrooms sustained major damage (i.e., cracks on walls, significant cracks on doors and window corners, out of plum or tilting of building structure, cracks on pillars and beams, significant cracks on infill walls), and about 8% (i.e., 18,436) of classrooms sustained minor damage (i.e., minor/hair cracks on building corners and door and windows, minor cracks on infill wall, and no damage on beams and pillars in case of framed structure building.

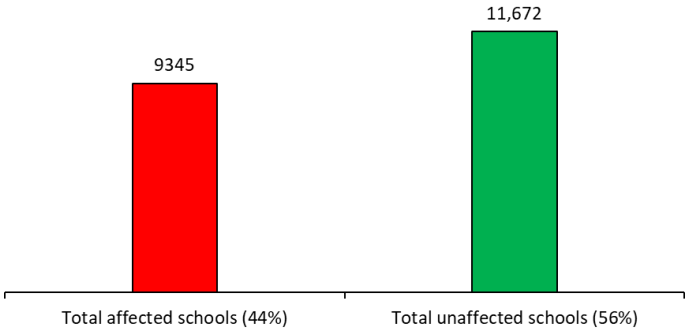


Figure 5. Percentage of affected and unaffected schools in the 53 districts surveyed in this study.

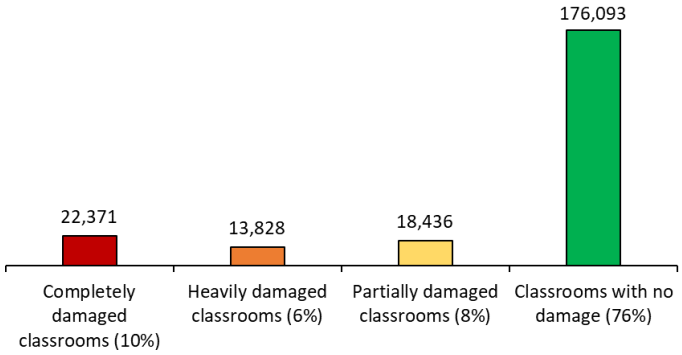


Figure 6. Observed damage levels of the school buildings in the 53 surveyed districts.

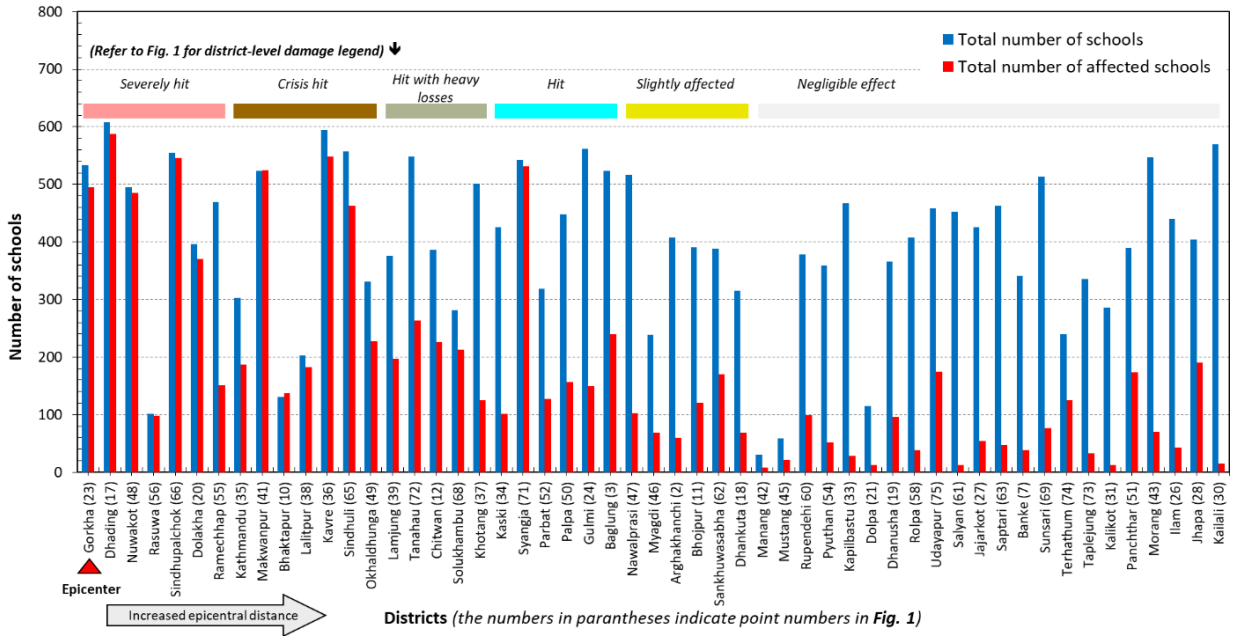


Figure 7. Total number of schools and the number affected by the earthquake in the 53 districts.

In general, earthquake shaking or intensity is negatively correlated to the distance from the epicenter, and we could expect that the damage ratio would have been greater in areas close to the epicenter than those farther from the epicenter. From Figure 7, it is more or less evident that this holds true except for a few cases of heavy damage in farther districts and less damage in closer districts. Figure 1 also indicates that the effect of the 2015 Nepal Earthquake is more prominent in eastward districts than the westside districts irrespective of the epicentral distance. This more pronounced damage (or shaking) in the

eastern parts than the western has been attributed to the directivity effect of the 2015 Nepal Earthquake [21].

3.2. Rapid Damage Assessment in the 14 Most-Affected Districts

According to the annual Flash Report 2015 published by Nepal's Department of Education [19], in the 14 most-affected districts, there are 5799 schools, 924,929 students, 15,353 school buildings, and 60,798 classrooms. The post-earthquake survey data indicate that nearly 5000 (i.e., 87%) of these schools were affected by the earthquake, as shown in Figure 8. Figure 9 shows the district-wise distribution of the schools affected by the earthquake, and Figures 10 and 11 show the status of classroom damage of the affected schools in the 14 districts consisting of more than 18,000 (i.e., 30%) collapses (or fully damaged), more than 8000 (i.e., 13%) major damages, and more than 10,000 (i.e., 17%) minor damages. The level of damage to the school buildings in terms of affected classrooms in some of the severely hit districts, such as Gorkha, Sindhupalchowk, and Nuwakot (Figure 11) is comparatively prominent in terms of ratio of completely damaged classrooms. The damage data indicate that about a total of 1411 (about 97%) out of 1448 schools were affected by the earthquake in these three districts. It was also found that a total of 7838 (about 54%) classrooms were completely damaged, 2463 (about 17%) classrooms sustained major damage, and 1887 (about 13%) classrooms sustained minor damage in the same three districts (refer to Figure 10). These figures indicate the high vulnerability of school buildings in those localities.

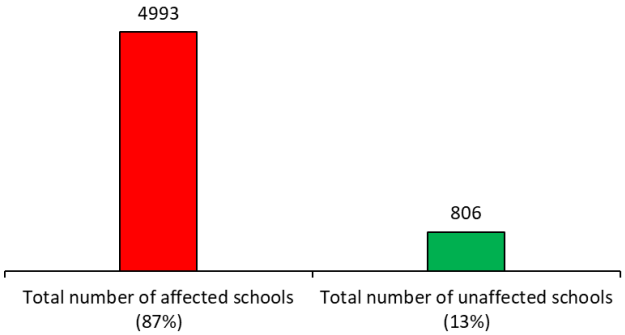


Figure 8. Percentage of the affected schools in the 14 most-affected districts.

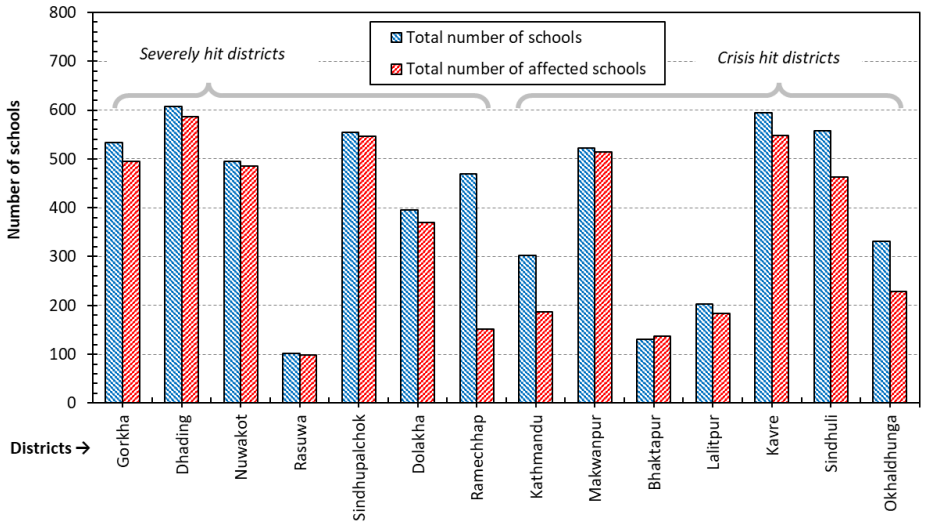


Figure 9. Distribution of the total number and the affected number of schools in the 14 most-affected districts.

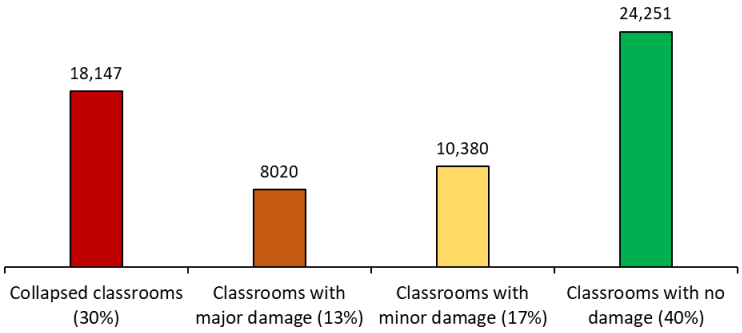


Figure 10. Distribution of damage level of the classrooms in the 14 most-affected districts.

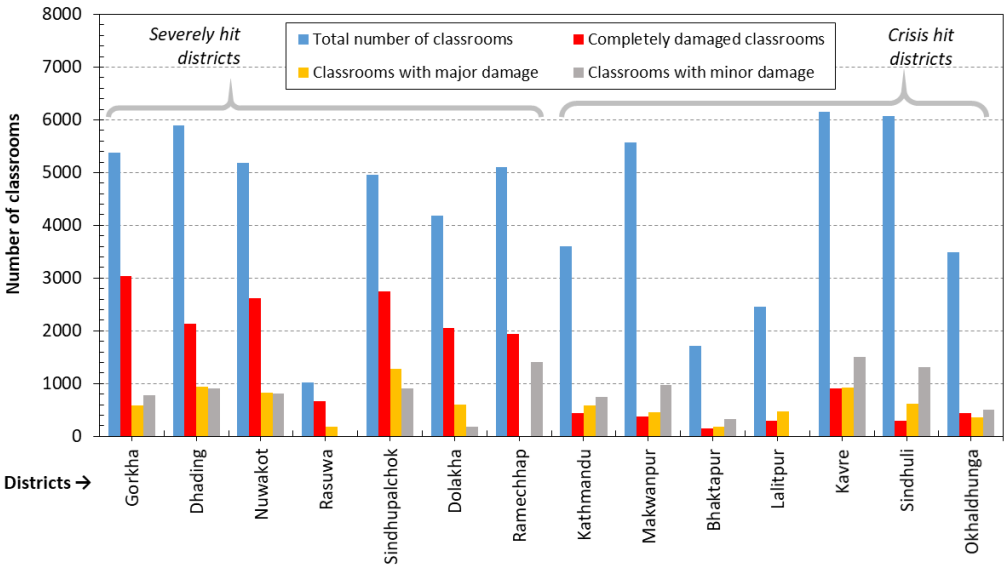


Figure 11. District-wise distribution of the classroom damage levels in the 14 most-affected districts.

An analysis of the available data in the 14 most-affected districts (refer to Figure 1) revealed that there were 61% of classrooms built of load bearing masonry walls, about 21% of classrooms built of reinforced concrete (RC) framed structure, about 14% of classrooms built of steel framed structure, and about 4% of classrooms built of other materials such as timber, thatch, etc., as indicated in Figures 12 and 13. Moreover, an analysis of the material type used in the classroom wall construction revealed that about 49% were built of stone in mud, about 31% built of brick in cement, about 8% built of stone in cement, about 4% built of brick in mud, about 1% built of bamboo, and only 0.2% were adobe, as presented in Figure 14. These figures are evidence that the majority of the school buildings in the most-affected districts were constructed of load bearing masonry walls (refer to Figures 12 and 13) and the majority of the walls were built of stone with mud mortar (refer to Figure 14), of which both are highly vulnerable to earthquake shaking. Moreover, the school buildings built of stone and brick masonry walls in mud mortar were damaged very heavily, whereas those built of brick masonry in cement–sand mortar, reinforced concrete (RC) frame, and steel frame were only partially damaged. From the building damage pattern in the earthquake-affected areas, it can be interpreted well that the main issues associated with the building collapse are poor quality construction materials, delamination of the walls, lack of diaphragm, re-entrant corner, wall junction failures, lack of seismic bands, mixed construction method (i.e., ground-floor stone masonry and upper-floor brick masonry), lack of integrity between different structural members/elements, failure of beam column joint, etc.

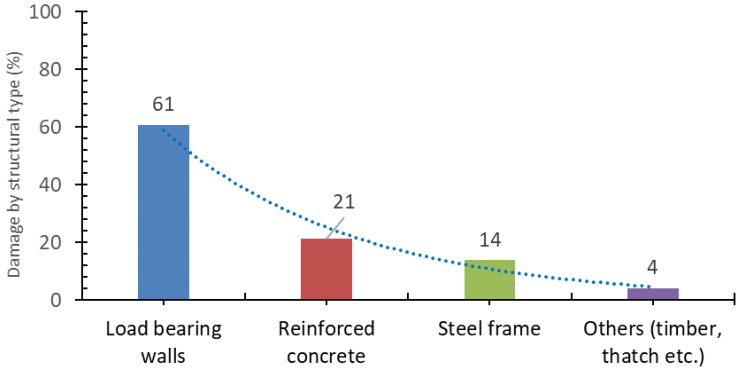


Figure 12. Damage to classrooms in the 14 most-affected districts by structural type.

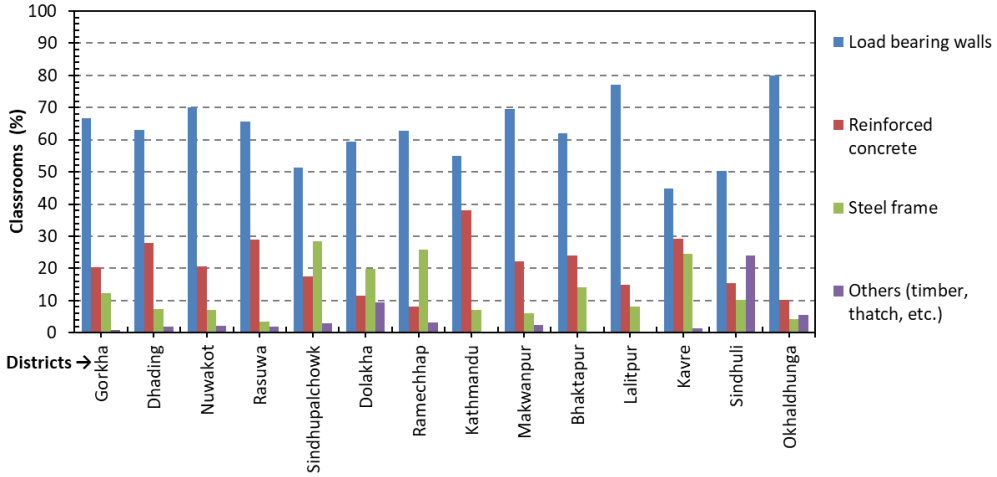


Figure 13. District-wise scenario of classroom types in terms of the material used in construction in the 14 most-affected districts.

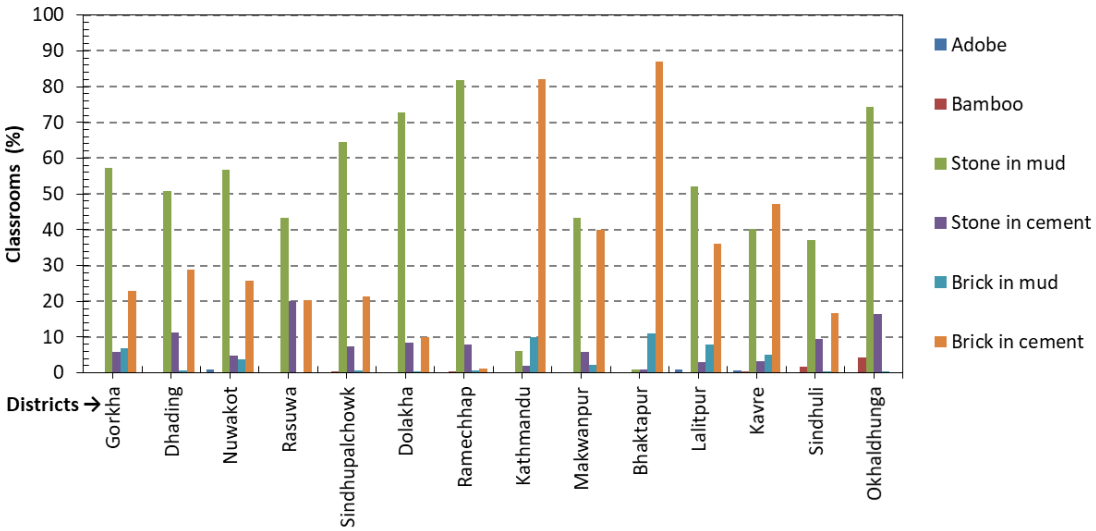


Figure 14. District-wise scenario of classroom wall types in the 14 most-affected districts.

3.3. Rebuilding Experience

Nepal still lacks a comprehensive policy to guide planning, design, and construction of school buildings. Many school buildings, even today, are constructed by the communities without following any design standards, construction guidelines, and technical supervision. The management of public schools is largely a responsibility of the local communities. The

government provides minimum financial support to run the schools while the communities must manage the rest. As the school management committees always tend to run the schools with inadequate annual budget, it increases the likelihood that poor construction materials and poor workmanship are used in constructing the school buildings, which makes them quite vulnerable to earthquake shaking.

In addition, most rural school buildings are constructed of locally available materials, such as adobe, stone rubble in mud mortar, or brick in mud mortar. Maintenance and repair work are also not common. Site specific hazard and risk analyses [22,23] are also not considered during design and construction. Although some model building designs are available, they are not entirely suitable for all locations. Therefore, formulation and implementation of an appropriate policy as well as a strategic plan is necessary for an improved seismic safety of school buildings, especially after the 2015 Nepal Earthquake. So, planning the rebuilding of the school, with new construction and retrofitting, or maintaining hundreds of thousands affected school buildings, such as by adopting the Build Back Better [24] approach within a limited period of 3 to 5 years, was almost impossible from the existing government resources. Nevertheless, there was an urgent need of reconstruction and retrofit of existing earthquake-damaged or vulnerable school buildings to ensure the safety of a huge number of school-going children and protect the properties from expected future earthquakes.

Two options for improving the seismic safety of school buildings might have been the following: (1) demolishing the existing vulnerable buildings and replacing them by new buildings and (2) retrofitting or seismic strengthening of the partially damaged or vulnerable buildings. The first one is obviously easy and attractive from a technical point of view, but it may be uneconomical [9,25] and less feasible not only because of the cost involved but also due to the magnitude and duration of the disturbance in the functioning of the schools. The duration of construction-related disturbance is normally estimated to be four to five times longer in the first option (i.e., about one year) than in the second one (i.e., 2–3 months) [9,25]. The second option is economical, attractive, and new. It also provides a good opportunity of more learning for the community, school management committee, teachers, and students [25–28]. Moreover, implementation of the school reconstruction/retrofitting program through the second option would also provide an opportunity for social dialogue, increased awareness, preparedness planning, and mason training, thereby, creating an opportunity of replication and hence inculcating a culture of safety in the community as well [29,30].

So, the reconstruction of hundreds of thousands damaged school buildings at once was very challenging for the government mainly because it required tremendous financial resources, a large number of construction companies, adequate technical manpower to supervise the construction activities, adequate quality control mechanism, such as a material testing laboratory, and enough construction materials, all of which are almost impossible in a developing country like Nepal. It was hardly possible for the Government of Nepal to allocate immense financial resources only for the purpose of new construction and retrofitting of the school buildings. However, the reconstruction of the school buildings and the retrofitting the existing vulnerable buildings (i.e., damaged, partially damaged) after the 2015 Nepal Earthquake were undoubtedly an urgent need to ensure an appropriate teaching and learning environment in the schools, as soon as possible.

After the 2015 Nepal Earthquake, it was necessary for the government to implement a school rebuilding program with minimum cost without compromising the structural safety of the school buildings. For this, timely formulation of an appropriate reconstruction plan and its implementation were an important step. So, based on the status and extent of damage to the school buildings in the 14 most-affected districts, a reconstruction plan was formulated and implemented through the government's reconstruction authority. The school reconstruction plan is presented in a process-flow format in Figure 15, and the details of the main steps and actions in the adopted rebuilding plan are described in the following sub-sections.

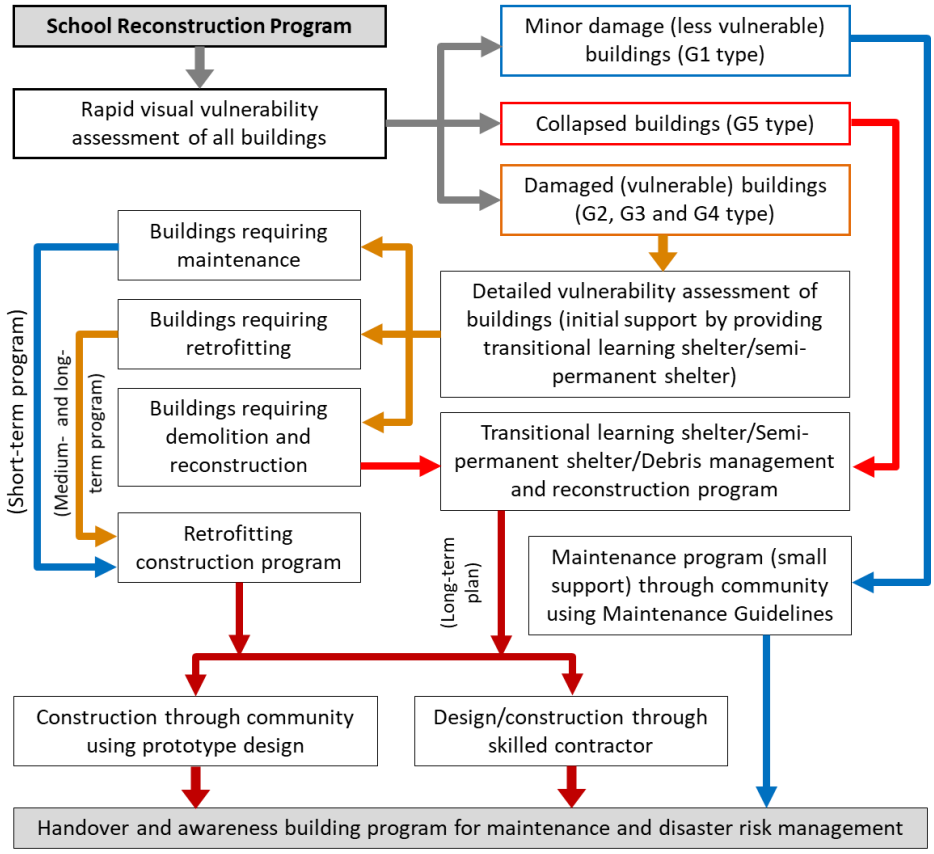


Figure 15. Reconstruction plan for the school buildings after the 2015 Nepal Earthquake. The colors of the lines indicate the length of the reconstruction plan (Blue: short-term program, Orange: medium- to long-term program, and Red: long-term plan).

3.3.1. Rapid Visual Vulnerability Assessment

As a quick method of easily identifying the damaged buildings that might pose a risk of life or injury, the rapid visual vulnerability assessment is a reliable method for seismic vulnerability assessment of buildings. This method mainly helps determine the need of more sophisticated and detailed seismic vulnerability assessment [31] and is also useful in shortlisting the buildings to which simplified vulnerability assessment procedure should be applied. The rapid visual screening method is designed to be implemented in ranking the school seismic strengthening needs without performing any structural calculations. In this step, as also mentioned elsewhere in the methodology section, the damage grades mentioned in the European Macroseismic Scale 1998, Vol. 15 (Table 1) [20] were adopted in categorizing the school buildings in the affected districts into the following three types:

- Minor damage buildings (less vulnerable)—Grade 1 (G1) type
- Damaged buildings (vulnerable)—Grade 2 (G2), Grade 3 (G3) and Grade 4 (G4) type
- Collapsed buildings—Grade 5 (G5) type

Using the rapid visual vulnerability assessment data, the "Collapsed buildings" were shortlisted and at the same time, a debris management plan was made. Then, the reconstruction plan for the new buildings was formed. As a transitional arrangement for running the classes in the collapsed school locations, temporary or semi-permanent classrooms were built as per requirements. Likewise, a list of "Minor damage buildings" (i.e., G1 type based on the EMS-98) requiring only minor repair work was prepared, which was carried out by simply following the maintenance guidelines with minimum financial support from the government and community. However, the "Damaged buildings" (i.e., G2, G4 and G5 type as per the EMS-98) needed further investigation because they were highly vulnerable to collapse, and it was not easy to ascertain the exact state of damage level

by only going through the rapid visual vulnerability assessment. Those school buildings that sustained partial damage (i.e., vulnerable buildings) were supported by temporary or semi-permanent classrooms as a transitional arrangement to run the classes until the damaged buildings could be retrofitted. This way, the rapid visual vulnerability assessment was an important activity for the first screening of the building damage.

3.3.2. Detailed Vulnerability Assessment

The detailed vulnerability assessment was aimed at "Damaged buildings" (i.e., vulnerable buildings; G2, G3, and G4 type as per EMS-98), as identified in the rapid visual vulnerability assessment. This method utilizes engineering information such as size and strength of lateral load of resisting members and more explicit information on the design of ground motion. These data are used for carrying out a highly simplified analysis of building structures in order to estimate the building drift. Since a good correlation exists between building drift and damage, the analysis results can be used to estimate the potential seismic risk of the buildings. From this analysis method, we can make an appropriate decision on the retrofitting methods to be used in strengthening the structural members. So, using the detailed vulnerability assessment method, we developed a detailed program and implementation modality for retrofitting the school buildings. This also helped to reduce the cost of preventative measures used, without compromising the structural safety of the buildings.

The detailed vulnerability assessment helped to identify the most critical buildings that needed a retrofitting/strengthening program, which were categorized in the following three ways based on the urgency of the retrofitting program:

- Buildings requiring minor retrofitting or retro-maintenance program
- Buildings requiring retrofitting program
- Buildings requiring demolition, debris management, and reconstruction program

Based on the availability of budget and manpower, a phase-wise implementation plan was also prepared. Priority went to the school buildings that required immediate retrofitting.

3.3.3. Reconstruction and Retrofitting Stage

For the maintenance or retro-maintenance of the damaged school buildings, the communities made a short-term plan with a little support from the government using retro-maintenance or maintenance guidelines. Retrofitting and reconstruction of the damaged school buildings, however, may need longer time and may require immense financial resources. So, for retrofitting and reconstruction, medium- to long-term programs (refer to Figure 15) were made.

Reconstruction and retrofitting of the school buildings were mainly conducted in two ways: (1) construction through a contractor (i.e., construction firm) and (2) construction through communities (i.e., implemented by the school management committee, SMC). From the technical point of view, the construction using a registered contractor was preferred over the construction through communities. As schools are not only for basic education but may also be used as emergency shelters during and after disasters, the school buildings must be disaster resilient. Moreover, retrofitting or reconstruction of complex or big buildings necessitates adequate technical knowledge, which cannot be overlooked. Only qualified and registered construction contractors can perform these works. These works also need intensive construction supervision by well-trained technicians. Nevertheless, for the construction and retrofitting of small sized and structurally simple school buildings (e.g., one to two story), the communities can be asked to carry out the job using a prototype design. In this case, construction supervision must be conducted by trained technicians, which helps to make the constructed facilities disaster resilient. Separate provisions for material quality testing and the construction quality control mechanism are prerequisite to maintain and assure the specifications of the constructed facilities. Moreover, a strong school construction management mechanism is also necessary to run the construction project without any delays.

For small-sized schools (i.e., number of students $\leq$ 200), the SMC and INGOs/NGOs modality of reconstruction (in which the communities were directly involved) was adopted and the reconstruction was conducted in incremental basis while for the bigger schools (i.e., number of students > 200) the damaged buildings were reconstructed by hiring the contractors. In the smaller schools, priority was given to rebuilding the classrooms while in the bigger schools, apart from rebuilding the damaged classrooms, the facilities like laboratory, library, computer lab, music room, teachers' rooms, separate toilets for boys and girls, toilets for physically-disabled students, water taps, furniture, solar backup, fencing, footpaths and gates, etc., as per the specific needs identified in the project design, were also built.

One of the advantages of community involvement in school building reconstruction and retrofitting programs is the potential reduction in the project cost. Local community people can contribute to the programs by providing donations or self-labor. In a developing country like Nepal, the community participation in these programs largely aids in reducing the project cost. It also helps to make the project sustainable. By involving the community, the financial transparency of the programs is also ensured since the involved community members are regularly informed of the financial issues, such as the amounts received from different sources and spent in different construction activities. In this way, they feel that the projects belong to them and involve themselves in maintenance of the constructed facilities in long-run efforts.

3.3.4. Awareness Building Program for Community Participation in Maintenance

As also highlighted by Shaw et al. [27], Tanaka [28], and Sharma and Gupta [29], disaster prevention is a cultural issue. To build a culture of disaster prevention, various programs and international campaigns have been launched in different parts of the world, but in some of the most vulnerable and disaster-prone areas, there are still a large set of factors that must be addressed for this purpose. In addition to making various efforts to reduce loss of life, destruction of property, and disruption of society and economy, the objectives of disaster prevention programs also include building safer communities, particularly focusing on community participation in disaster prevention efforts, training programs for local masons and technicians, and disaster prevention-related training programs for students, teachers, and communities, e.g., [32–37].

So, during the reconstruction phase and after handing the reconstructed schools over to the communities, awareness building programs were frequently held, which mainly included direct involvement of communities in reconstruction activities, seminars to make the local stakeholders understand the disaster risk and school disaster safety, regular maintenance and repair trainings, etc.

Community participation in disaster prevention programs also has various challenges, such as how to improve the communities' understanding of the risk they face, how to empower them with abilities to act towards reducing the risk, how to manage the consequences of a disaster, etc. Yet, community engagement in school reconstruction programs builds a trust of the locals in the ongoing reconstruction activities. Without their involvement, the reconstruction program implementation may be sometimes misunderstood. Paci-Green et al. [33] conducted a survey in this relation after the 2015 Nepal Earthquake. They reported that the community-engaged projects showed better knowledge of disaster risk and earthquake-resistant construction technology in people. Moreover, they developed a tendency to advocate safer construction practice after the 2015 Nepal Earthquake. It is also evident that community engagement and awareness of building during the school building reconstruction programs are very important. So, community engagement in reconstruction program not only helps to reduce the project cost but also helps to make it sustainable and raises peoples' awareness level on disasters, their impact, and their preventative measures.

4. Concluding Remarks

About 9000 schools were affected by the 2015 Nepal Earthquake. Preliminary damage assessment showed that in the 14 most-affected administrative districts, about 86% of the total number of schools were affected and about one million students were out of the schools for a long time. Of the 86% affected schools and their total of 60,798 classrooms, about 30% of classrooms were completely damaged, about 13% sustained major damage, and about 17% sustained minor damage. All this led to a serious challenge to the planning reconstruction program for such a huge number of school buildings at the same time. The need for immense financial resources, a large number of construction contractors, and trained technical manpower to supervise the construction activities, an efficient quality control mechanism, and the availability of enough construction material were the major issues confronted during the reconstruction planning. In this paper, based on the damage data and the steps of experience in rebuilding the school buildings after the 2015 Nepal Earthquake, the three main steps in the school reconstruction plan are highlighted below.

First, a rapid visual seismic vulnerability assessment of the affected school buildings was conducted to quickly identify the buildings that might pose a risk of life and injury, and to categorize the buildings into different groups, such as collapse/fully-damaged buildings, partial-damage/vulnerable buildings requiring seismic strengthening, and less-vulnerable buildings requiring only minor repair and maintenance programs.

Second, a detailed vulnerability assessment was performed for the partial-damage/vulnerable buildings so that they could be categorized as per the type of retrofitting techniques necessary and the financial resources required for implementing the retrofitting program. This helped in launching the program in priority order as per the urgency of retrofitting works in the schools.

Third, the reconstruction and retrofitting program was designed in such a way that it would enhance community participation in all the stages of program implementation, i.e., from the planning stage to reconstruction and maintenance stages of the school buildings. It was emphasized that community engagement in a construction program improves the local people's knowledge of risk of disasters and earthquake-resistant construction technology, and they develop a tendency to advocate for safer construction practice, targeting any expected future earthquake disasters in Nepal. Community participation not only helps to reduce the cost of the project but also helps to make it sustainable and raises people's awareness of disasters, their impact, and the preventative measures.

The whole Himalaya Region as well as the Nepal Himalaya experience frequent earthquakes. So, to prepare for any future earthquakes, sharing of experiences of pre- and post-disaster activities including the reconstruction and rebuilding plan is always important in creating disaster-safe and disaster-resilient communities. The recent past earthquake disasters in the region as well as in other parts of the world are evident that economically weak nations are hit the hardest and lose the most because they are less prepared and less resilient to natural disasters. Moreover, most mountainous settlements in the Himalaya Region use less earthquake-resistant building materials and construction methods, which make these regions more and more vulnerable to earthquake damage. To reduce any future earthquake damage, the assessment and retrofitting of vulnerable buildings in unaffected areas are as important as using earthquake-resistant materials and the building techniques in the affected areas. The experience of rebuilding and reconstructing the school buildings after the 2015 Nepal Earthquake reported in this paper is also intended to function as a reference for other seismically vulnerable parts of the world.

Author Contributions: Y.R.P. compiled data and performed the analysis. He also drafted the manuscript. N.P.B. gave suggestions on methodology and conclusions. N.P.B. also revised the manuscript and reorganized the overall structure. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: All the data and materials used are mentioned in the manuscript.

Acknowledgments: This study was carried out with the help of the officials from the Government of Nepal's Department of Education (DOE). Jhapper Singh Vishwakarma of the DOE and Jimi Oostrum of UNICEF are acknowledged for their support and suggestions during the preparation of the manuscript. In addition the Japan Student Services Organization (JASSO) fellowship provided to the first author (Research Advisor: Ryuichi Yatabe, Ehime University, 2016) after the 2015 Nepal Earthquake is sincerely acknowledged.

Conflicts of Interest: The authors declare that they have no conflict of interest.

References

1. *Nepal Disaster Risk Reduction Portal*; Nepal Disaster Report 2015; Government of Nepal, Ministry of Home Affairs: Kathmandu, Nepal, 2015; pp. 13–22. Available online: http://drrportal.gov.np/document/documentdetail/329 (accessed on 10 October 2023).
2. *Nepal Earthquake 2015, Post Disaster Needs Assessment*; Government of Nepal, Ministry of Home Affairs: Kathmandu, Nepal, 2015; Volume A: Key Findings; pp. 11–13. Available online: https://npc.gov.np/images/category/PDNA_Volume_A.pdf (accessed on 10 October 2023).
3. Fajfar, P.; Gaspersic, P. The N2 method for the seismic damage analysis of RC buildings. *Earthq. Eng. Struct. Dyn.* **1996**, *25*, 31–46. [CrossRef]
4. Di Ludovico, M.; Digrisolo, A.; Moroni, C.; Graziotti, F.; Manfredi, V.; Prota, A.; Dolce, M.; Manfredi, G. Remarks on damage and response of school buildings after the Central Italy earthquake sequence. *Bull. Earthq. Eng.* **2019**, *17*, 5679–5700. [CrossRef]
5. Ruggieri, S.; Perrone, D.; Leone, M.; Uva, G.; Aiello, M.A. A prioritization RVS methodology for the seismic risk assessment of RC school buildings. *Int. Disaster Risk Reduct.* **2020**, *54*, 101807. [CrossRef]
6. Giordano, N.; De Luca, F.; Sextos, A.; Cortes, F.R.; Carina Fonseca Ferreira, C.F.; Wu, J. Empirical seismic fragility models for Nepalese school buildings. *Nat. Hazards* **2021**, *105*, 339–362. [CrossRef]
7. Ruggieri, S.; Porco, F.; Uva, G.; Vamvatsikos, D. Two frugal options to assess class fragility and seismic safety for low-rise reinforced concrete school buildings in Southern Italy. *Bull. Earthq. Eng.* **2021**, *19*, 1415–1439. [CrossRef]
8. *Seismic Vulnerability of the Public School Buildings of Kathmandu Valley and Methods for Reducing It: A Report on the School Earthquake Safety Program of the Kathmandu Valley Earthquake Risk Management Project*; National Society for Earthquake Technology: Kathmandu, Nepal, 2000; p. 60. Available online: https://nset.org.np/nset2012/images/publicationfile/20130724114208.pdf (accessed on 10 October 2023).
9. Dixit, A.M.; Yatabe, R.; Dahal, R.K.; Bhandary, N.P. Public School Earthquake Safety Program in Nepal. *Geomat. Nat. Hazards Risk* **2014**, *5*, 293–319. [CrossRef]
10. Ghazoui, Z.; Bertrand, S.; Vanneste, K.; Yokoyama, Y.; Nomade, J.; Gajurel, A.P.; van der Beek, P.A. Potentially large post-1505 AD earthquakes in western Nepal revealed by a lake sediment record. *Nat. Commun.* **2019**, *10*, 2258. [CrossRef] [PubMed]
11. Paudyal, Y.R.; Bhandary, N.P.; Yatabe, R. Seismic microzonation of densely populated area of Kathmandu Valley of Nepal using microtremor observations. *J. Earthq. Eng.* **2012**, *16*, 1208–1229. [CrossRef]
12. Ader, T.; Avouac, J.P.; Liu-Zeng, J.; Lyon-Caen, H.; Bollinger, L.; Galetzka, J.; Genrich, J.; Thomas, M.; Chanard, K.; Sapkota, S.N.; et al. Convergence rate across the Nepal Himalaya and interseismic coupling on the Main Himalayan Thrust: Implications for seismic hazard. *J. Geophys. Res.* **2012**, *117*, B04403. [CrossRef]
13. Ruggieri, S.; Chatzidaki, A.; Vamvatsikos, D.; Uva, G. Reduced-order models for the seismic assessment of plan-irregular low-rise frame buildings. *Earthq. Engng. Struct. Dyn.* **2022**, *51*, 3327–3346. [CrossRef]
14. Galanis, P.H.; Moehle, J.P. Development of collapse indicators for risk assessment of older-type reinforced concrete buildings. *Earthq. Spectra.* **2015**, *31*, 1991–2006. [CrossRef]
15. Masi, A.; Santarsiero, G.; Chiauzzi, L. Development of a seismic risk mitigation methodology for public buildings applied to the hospitals of Basilicata region (Southern Italy). *Soil Dyn. Earthq. Eng.* **2014**, *65*, 30–42. [CrossRef]
16. Silva, V.; Crowley, H.; Varum, H.; Pinho, R.; Sousa, L. Investigation of the characteristics of Portuguese regular moment-frame RC buildings and development of a vulnerability model. *Bull. Earthq. Eng.* **2014**, *13*, 1455–1490. [CrossRef]
17. Jalayer, F.; Franchin, P.; Pinto, P.E. A scalar damage measure for seismic reliability analysis of RC frames. *Earthq. Eng. Struct. Dyn.* **2007**, *36*, 2059–2079. [CrossRef]
18. Saokota, R. Better and Stronger Schools. Rebuilding Nepal, a National Reconstruction Authority Publication. 2021 (December Issue); National Reconstruction Authority, Nepal. Available online: http://www.nra.gov.np/en/content/bulletins/0 (accessed on 10 October 2023).
19. *Flash I Report 2072 (2015–2016)*; Department of Education, Ministry of Education, Government of Nepal: Kathmandu, Nepal, 2015. Available online: https://www.doe.gov.np/category/flash-reports.html (accessed on 10 October 2023).
20. Grünthal, G. (Ed.) *European Macroseismic Scale 1998 (EMS-98)*; European Seismological Commission: Luxembourg, 1998; Volume 15. Available online: https://media.gfz-potsdam.de/gfz/sec26/resources/documents/PDF/EMS-98_Original_englisch.pdf (accessed on 10 October 2023).

21. Koketsu, K.; Miyake, H.; Guo, Y.; Kobayashi, H.; Masuda, T.; Davuluri, S.; Bhattarai, M.; Adhikari, L.B.; Sapkota, S.N. Widespread ground motion distribution caused by rupture directivity during the 2015 Gorkha, Nepal earthquake. *Sci. Rep.* **2016**, *6*, 28536. [CrossRef] [PubMed]
22. Bhandary, N.P.; Paudyal, Y.R.; Okamura, M. Resonance effect on shaking of tall buildings in Kathmandu Valley during the 2015 Gorkha earthquake in Nepal. *Environ. Earth Sci* **2021**, *80*, 459. [CrossRef]
23. Takai, N.; Shigefuji, M.; Rajaure, S.; Bijukchhen, S.; Ichiyanagi, M.; Dhital, M.R.; Sasatani, T. Strong ground motion in the Kathmandu Valley during the 2015 Gorkha, Nepal, earthquake. *J. Earth Planets Space* **2016**, *68*, 10. [CrossRef]
24. Sendai Framework for Disaster Risk Reduction 2015–2030. United Nations International Strategy for Disaster Reduction. Available online: https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf (accessed on 10 October 2023).
25. Vishokarma, J.S.; Dahal, R.H.; Acharya, S.P.; Guragain, R.; Dixit, A.M. Implementing school retrofitting program in Nepal: Experiences and lessons learnt. In Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal, 24–28 September 2012; Volume 29, pp. 22945–22955.
26. Cardona, O.D. Curriculum Adaptation and Disaster Prevention in Colombia. In *International Perspectives on Natural Disasters: Occurrence, Mitigation, and Consequences*; Lidstone, J., Dechano, L.M., Stoltman, J.P., Eds.; Springer: Dordrecht, The Netherlands, 2007; Volume 21. [CrossRef]
27. Shaw, R.; Shiwaku, K.; Kobayashi, H.; Kobayashi, M. Linking experience, education, perception and earthquake preparedness. *Disaster Prev. Manag.* **2004**, *13*, 39–49. [CrossRef]
28. Tanaka, K. The impact of disaster education on public preparation and mitigation for earthquakes: A cross-country comparison between Fukui, Japan and the San Francisco Bay Area, California, USA. *Appl. Geogr.* **2005**, *25*, 201–225. [CrossRef]
29. Sharma, A.; Gupta, M. Building community resilience through education: School safety as a route to a culture of prevention. *Reg. Dev. Dialogue* **2007**, *28*, 23–32.
30. *Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters*; United Nations International Strategy for Disaster Reduction: Geneva, Switzerland, 2005. Available online: https://www.unisdr.org/2005/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf (accessed on 10 October 2023).
31. Paudyal, Y.R.; Subedi, J.; Shrestha, R. Rapid Visual Seismic Vulnerability Assessment Tool for Kathmandu Valley. *Tech. J.* **2009**, 100–108.
32. Ando, S.; Pandey, B.H.; Fujieda, A. Making schools safe from earthquakes through retrofitting, training, and disaster education: A case study of the UNCRD SESI Project. *Reg. Dev. Dialogue* **2007**, *28*, 131–141.
33. Paci-Green, R.; Pandey, B.; Friedman, R. Safer Schools, Resilient Communities: A Comparative Assessment of School Safety after the 2015 Nepal Earthquakes. Risk RED. 2015. Available online: https://cenv.wwu.edu/files/2021-01/SaferSchoolAssess-NepalRiskRED-highres.pdf (accessed on 10 October 2023).
34. Parajuli, R. Citizen Disaster Science Education for effective disaster risk reduction in developing countries. *Geoenvironmental Disasters* **2020**, *7*, 12. [CrossRef]
35. Ronan, K.R.; Crellin, K.; Johnston, D. Correlates of hazards education for youth: A replication study. *Nat. Hazards* **2010**, *53*, 503–526. [CrossRef]
36. Tuladhar, G.; Yatabe, R.; Dahal, R.K.; Bhandary, N.P. Knowledge of disaster risk reduction among school students in Nepal. *Geomat. Nat. Hazards Risk* **2014**, *5*, 190–207. [CrossRef]
37. Takeuchi, Y.; Mulyasari, F.; Shaw, R. Roles of Family and Community in Disaster Education. In *Community, Environment and Disaster Risk Management*; Shaw, R., Takeuchi, K.S.Y., Eds.; Emerald Group Publishing Limited: Bingley, UK, 2011; pp. 77–94. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.