SAFER: Improving seismic resilience of schools and educational communities

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ABSTRACT: After a natural disaster it is typical for most efforts to focus on shelter, recovery and reconstruction without due consideration of a wider framework for building back better buildings and at the same time creating infrastructure and institutions that are resilient to different shocks and stresses. Our large-scale research, through SAFER Nepal project (www.safernepal.net), has addressed this need through the development of a SAFER toolbox for improving the earthquake-related safety of school buildings and for enabling the educational communities to find their own pathways to become resilient against a range of hazards. This requires a holistic framework for the pre- and post-earthquake assessment of school buildings under a standardised procedure which is easy to use by the stakeholders including local authorities. Such a framework has been built into the SAFER toolbox thus enabling prioritisation of school buildings, based on statistical data, for retrofitting and adaptation measures at different geographic scales. The scoring procedure used here is capable of incorporating relevant data for any country. SAFER also offers a framework and a mobile app for the evaluation of resilience of an educational community. This consists of fourteen indicators with associated set of questions for each category of educational stakeholder. All the questions with objective responses are quantified and an overall educational community resilience index is calculated. The mobile app can be used by the educational community for the self-assessment of schools and track their resilience with time.

1. INTRODUCTION

The sustainability of school infrastructure and the resilience of the educational communities to natural hazards is of paramount importance to provide the safety and protection from the various natural and man-made threats children face. As an example, during the 2015 Nepal earthquake (Rai et al, 2016) over 600,000 buildings were destroyed, including 19,700 collapsed classrooms in 8,620 schools and an estimated 3.2 million children were displaced (Government of Nepal, 2015). To address this, our SAFER project has taken a holistic approach to resilience of schools, from physical infrastructure to educational communities themselves. Typical assessments of schools generally focus on the structural condition evaluation considering one or more hazards in the region. Pre- and post-event structural inspection remains an issue in developed countries because it requires professionally trained and experienced local inspectors. This is even more challenging in the many developing countries such as Nepal and Malawi. Moreover, functioning of schools depends upon a range of other factors including governance and funding, provision of supporting infrastructure and more importantly, the resourcefulness of educational communities including teachers, pupils and parents (Parajuli et al, 2020). School community is the first agent to respond to any disaster event (Save the Children, 2015), hence their capacity to resist and cope with such events is as important as that of the school buildings.

Our research has produced a novel approach to the resilience assessment of schools and communities with a goal of "continuity of education under safe environment". The purpose of this paper is to introduce the key aspects of the school resilience framework developed so far and the associated SAFER mobile application.

The next two sections present the underlying concepts and methodology for structural assessment and community resilience assessment.

The subsequent section provides application examples from growing datasets from Nepal and Malawi before concluding the paper.

2. STRUCTURAL ASSESSMENT

Developments in pre- and post-earthquake assessment of buildings have seen rapid growth in countries exposed to high seismic risk due to the socio-economic costs of an earthquake. Pre-earthquake assessment of buildings is primarily aimed at the prioritisation of strengthening of public buildings such as schools and hospitals. The ranking of buildings is performed based on qualitative and/or quantitative criteria typically resulting in a 'score' (Sextos et al, 2008). It often starts with a rapid visual survey (RVS) before undertaking a detailed study of buildings identified as hazardous. A RVS can take different forms depending upon the country context, but one developed by the Federal Emergency Management Agency (FEMA) in the US (Federal Emergency Management Agency, 2015) is widely used. The different methodologies mainly differ in scoring parameters or their values depending upon the construction practices, building properties and construction quality. A post-earthquake RVS allows the local and national authorities to obtain a rapid view of the damage in terms of the degree of damage and its spatial distribution for recovery efforts.

The methodology presented here together with the corresponding mobile phone app and webapp is aimed at providing a low-cost solution for rapid visual survey of a large portfolio of buildings. This has been tailored to schools in Nepal, with minimum access to buildings, but can be easily adopted for other countries by updating the typologies, scoring matrix and the seismic hazard maps. It is worth emphasising that the purpose is not to evaluate the structural capacity of buildings in any way but to group them statistically in a few prioritisation categories. It is quite possible for a detailed inspection to find a building to be safe which was identified as unsafe by rapid screening. Further, both building vulnerability and hazard data is used for the assessment of a building, thus producing a measure of risk. The app has been tested during field campaigns in Nepal.

2.1. Scoring algorithm

The scoring algorithm used here is an adaptation of the widely used FEMA approach (FEMA, 2015) but it has been tailored to the building stock in Nepal. Similar to the FEMA approach, Basic Scores and Score modifiers are used to arrive at the Total Score. A higher score corresponds to better seismic performance and a lower probability of collapse under Maximum Considered Earthquake (MCE). Where building type-specific probabilities are not available, a simplified procedure with the following equations is used:

$$BS = BS_{ref}\, SZF \tag{1}$$

$$S = BS_{ref}\, SZF + SC + \sum_{i=1}^{N} SM_i \tag{2}$$

where BS_{ref} is the Reference Basic Score for the identified structural typologies, *SZF* is a Seismic Zone Factor representing the level of hazard, *SC* accounts for the soil conditions taking a value from 0 for rock, SM_i represents a Score Modifier (a negative value) corresponding to a structural weakness and *S* is the Total Score. The values of Reference Basic Score, which vary depending upon the number of storeys and mortar type also, have been assigned based on engineering judgement. All these values for Nepal have been specified in the technical manual and the key features are outlined below.

School buildings are classified in seven main categories based on their main structural system for resisting lateral forces. These are adobe, brick/stone in cement, non-engineered reinforced concrete moment-resisting frame, engineered reinforced concrete moment-resisting frame, or a combination of timber and other materials, following the previous investigations (NSET/GHI, 2000; Arup, 2013). They are then further classified according to the number of storeys and the mortar type (mud or cement) in the load bearing masonry walls or the infill panels in case of reinforced concrete buildings.

Table 1: Score Modifiers.

	Score modifier	*Range*	*Comments*
1	Building modification	0 to -0.3	Changes in load bearing mechanism
2	Previous seismic damage	-0.2 to -0.9	Reduced residual capacity
3	Poor maintenance	-1.0	
4	Likeliness of pounding	-0.5	Particularly where adjacent buildings' floors at different levels
5	Soft storey	0 to -1.5	Abrupt change of stiffness along height
6	Irregularity in height	0 to -0.8	Stiffness variation including setbacks
7	Irregularity in plan	0 to -0.8	
8	Torsion	0 to -0.5	Centre of stiffness and centre of mass eccentrically located
9	Short columns	0 to -1.5	Brittle behaviour in R/C buildings
10	Moisture and corrosion	-0.3	Significant corrosion
11	Corroded reinforcement	0 to -1.2	Localised corrosion of rebars
12	Poor concrete quality	0 to -1.0	Poor quality and detailing
13	Discontinuous or floating columns	0 to -1.2	Lack of reinforcement continuity from one storey to the other
14	Cut rebars	0 to -1.0	Loss of strength
15	Wall cracks	-0.5 masonry, -0.2 R/C	
16	Discontinuous column joints	0 to -1.0	
17	Concrete slab on masonry walls	0 to -0.6	Increased seismic force and out of plane failure of masonry wall
18	Construction on a slope	-0.5	Local site amplification
19	Construction practice	-0.5	Older buildings, for example
20	Weak masonry	0 to -0.6	

Twenty score modifiers have been defined to subtract points from the Basic Score. These are listed in Table 1. The values corresponding to different typologies and several examples are available in the technical manual.

The main differences from the FEMA approach are as follows: (a) Basic scores have a maximum of 10 instead of typical 7 in FEMA and score modifiers are always subtracted; (b) Basic scores have been tailored to the structural typologies of Nepalese buildings based on the their performance during the 2015 Gorkha earthquake; (c) Score modifiers reflect the deficiencies in Nepalese construction practice identified during recent fieldwork in Nepal; (d) The Basic Scores and Score Modifiers have been refined to account for the collapse probabilities of Nepalese buildings resulting from capacity curves and demand spectra.

Based on the final score, school buildings are statistically placed in three categories: A – unsafe or requiring immediate attention (typically lowest 20% of the scores), B – possibly unsafe (20% to 50% lower scores) and C – generally safe (upper 50% of the scores). The above features have been incorporated in SAFER mobile App (University of Bristol, 2021) and WebApp to produce tools for local engineers. These are also being enriched with data correction features by applying a series of filters and logical checks. The software can be used in other developing countries with minimal adaptations, as has already been done for Malawi.

3. COMMUNITY ASSESSMENT

To assess the resilience of schools and educational communities, SAFER framework allows capturing of local information on the school practices and school communities. Four major dimensions and corresponding 14 indicators, as shown in the Figure 1 and explained subsequently, were developed through a series of community engagement activities involving headteachers, school management committee members, teachers, pupils, parents/guardians and local communities in Nepal.

Figure 1: Resilience of schools: Dimensions and Indicators.

Based on the above framework, a practical tool for community resilience assessment has been developed. This has two main components – one, a questionnaire to gather evidence for each of the indicators and the other, a scoring algorithm for each indicator as well as an overall score. A matrix has been developed to map questionnaire responses to indicator scores which incorporates weights for different categories of stakeholders. The results are presented as a radial chart covering all the resilience indicators which can be used by the schools to design adaptive pathways to resilience.

3.1. Governance and funding

3.1.1. Preparation and training

This includes a set of questions specifically directed at identifying preparedness measures and plans in the school and nearby community to resist shocks and stresses. Planning to handle a higher number of pupils, activities for disaster preparedness including drills, early warning systems and other instruments in the community are represented under this indicator. All of this in turn will contribute to the scale of impact of a hazardous event and the rapidity of recovery.

3.1.2. Resources

The more resourceful a school and community is, the more resilient the school can be. A range of evidence can relate to resourcefulness. Funding is key to identify the appropriate preparedness and mitigation measures that can be put in place. Classroom sizes and student numbers, spare capacity of teachers, teaching and learning materials and their availability are also included here.

3.1.3. Governance

Good governance is important for robustness and recovery. This includes having a clearly laid out crisis plan for continuity of education. Participatory governance would be of great value where views of all key stakeholders are represented and the strengths and limitations of preparedness and mitigation measures can be derived from different perspectives. Status of resource planning, policies, safety measures at school premises are also assessed under this indicator.

3.2. School curriculum

3.2.1. Hazard education

This indicator shows whether the curriculum or the lessons cover the hazard education or not. Questions covered include the hazard education specific classes, drills and training as part of curriculum, knowledge and perception of hazards through educational offerings.

3.2.2. Richness and diversity

Different ways of addressing educational needs and well-being of children contribute to resilience. General state of stresses in classroom, richness of materials and methods, frequency of extracurricular activities are assessed under this indicator. This also reflects the delivery methods and the effectiveness of regular classes, flexibility of curriculum in incorporating hazard and risk mitigation plans in the school.

3.3. School community

3.3.1. Local culture

Local culture of the community in several aspects of social activities are influential in mobilising resources and recovery after any disaster. Local languages, practices on use of public facilities, value system, priority on the child education in the local community are represented through this.

3.3.2. Social cohesion

Social connectivity of children (and their families) has a positive impact on their well-being, especially in times of crisis. It is assumed that the more supportive their social environment is the more likely they are to continue their education. Engagement of other community members in school activities, relationships between teachers, students and parents, community contribution to school are represented under this indicator.

3.3.3. Health and well-being

Health and well-being of the school community contributes to the robustness, and rapidity in recovery. Cleanliness and hygiene at school, first aid kits and regular health check-up, lunch and meals, counselling are assessed through engagement with the school community.

3.3.4. Socio-economic state

Any evidence of social capacity, e.g. in terms of physical or economical, would contribute to resourcefulness. Social state of local community including parents, their strength on disaster risk awareness, preparedness and mitigation plans directly contribute to school resources. The ability to contribute to recovery through funding and voluntary activities are also included.

3.4. Infrastructure and environment

3.4.1. Ecosystem and environment

Shocks and stresses due to environment and ecosystem are identified. Disruptions in education as a result of local climate are assessed under this indicator. Risk mitigation measures and results are studied; it also shows the exposure of community to the hazards.

3.4.2. Access and use

The purpose here is to gauge the difficulty in getting to school by both the pupils and staff. It is assumed the bigger the school catchment, more difficult it may be to get to the school when conditions are not favourable e.g. heavy rain. A school can be a valuable asset for a community for holding community events and for shelter in times of crisis. Unless due measures are put in place, both these uses have the potential to cause disruption to education.

3.4.3. Non-structural health

Services and utilities in the school premises ultimately contribute towards several factors from health and well-being to quality of education. Hence, assessing the status of such facilities is one of the major perspectives in a resilient educational community. Water supply, sanitation, power supply, communication, thermal comfort etc. are assessed here.

3.4.4. Structural health

Information about the school buildings contributes to their vulnerability to hazards. Different pieces of information about school building are also helpful for an assessment of the rapidity of recovery following a disaster. Design, planning and construction quality, structure typology, age and general state of building is assessed. Disruption to continuity of education due to potential structural failure scenarios are also studied. Questions relating to quality control not only tell us about vulnerabilities but also guide what kind of preparedness measures and intervention schemes are needed against hazards.

4. APPLICATION EXAMPLES

To enhance the seismic safety of school buildings and the resilience of educational communities, two user-friendly applications have been developed: (i) an application for Android mobile devices which has two modules – one, for the field engineers to survey school buildings, collecting data and photographs, and the other, to gather questionnaire responses from the school community; (ii) a web application accessible from any browser to provide an hierarchical view of structural data or community data from multiple schools. Structural assessment and community resilience scores using these tools based on the methodology described above are presented for two schools – one in Nepal and the other in Malawi.

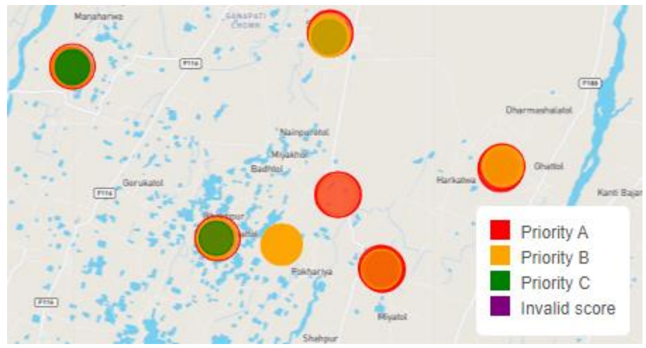
(a)

(b)

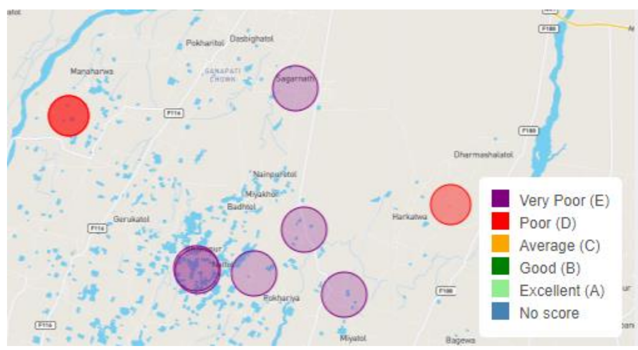
(c)

Figure 2: A school near Kathmandu, Nepal: (a) unreinforced masonry buildings in cement mortar (structural score 1.34-1.41), (b) unreinforced masonry building in mud mortar (structural score -0.53), (c) community resilience indicators (overall score 52/100).

Figure 2 shows a school in an area east of Kathmandu which suffered significant damage during the 2015 Nepal Earthquake. The school had four buildings - three of these were masonry in cement mortar (Fig 2(a)) with RVS scores of 1.3 - 1.4; one building (Fig 2(b)) in masonry with mud mortar resulted in a score of -0.53. Fig 2(c) shows the resilience indicator scores on a radial chart. The results of structural and community resilience assessment for a region can be visualised on a map, such as in Figure 3, to plan adaptation measures at regional and national level.



(a)



(b)

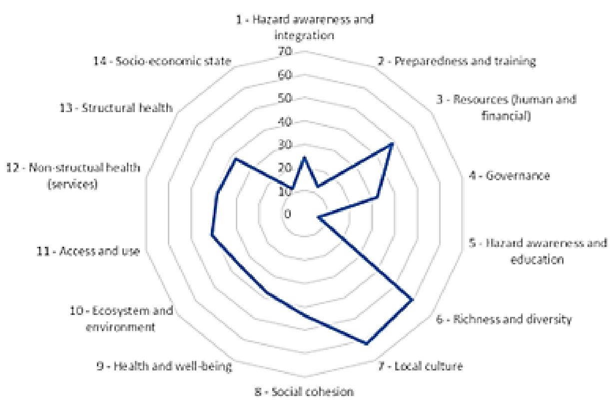
Figure 3: Example outputs for a region in Nepal: (a) structural assessment and (b) community resilience assessment

Figure 4 shows a school in the northern region of Malawi. Again, this was in unreinforced masonry in cement mortar but showed a relatively better structural assessment score of 3.0. The resilience indicators varied significantly resulting in an overall score of 36/100.

5. DISCUSSION

Data collection using tools presented above is an efficient way to identify the strengths and weaknesses of structures and community at a local, regional or national level. Such findings can make it easier to identify adaptative measures which would be most suited to the local conditions and can be facilitated through policy changes. For example, many of the weaknesses noticed in the buildings surveyed require increased awareness amongst builders and adherence to building regulations. Similarly, school communities can identify and prepare for alternative ways to maintain continuity of education during disruptive events.

(a)



(b)

Figure 4: A school in North region of Malawi: (a) unreinforced masonry buildings in cement mortar (score 3.0), (b) community resilience indicators (overall score 36/100).

The rapid visual inspection can be done using the app on a mobile phone and the data transferred to a central repository. A web interface has been developed to process this data to produce a GIS (Geographic Information System) map thus enabling quick visualisation of the spatial distribution of the school building vulnerability.

All data is managed centrally using MySQL database and downloadable pdf outputs can be generated for the relevant stakeholders. The application has been designed for ease of internationalization including scoring algorithms and language.

It is worth mentioning that the Rapid Visual Survey of school buildings we do is just preliminary to prioritize, on the basis of their relative risk (i.e., convoluting seismic hazard with vulnerability), the buildings that would need to be looked at in more detail by a second degree RVS. Therefore, a more detailed structural assessment is indeed prescribed, but naturally, only for the most risky school buildings, otherwise it is not feasible to be applied at a large scale.

Also, there are several works on community resilience offering different indicators and methodologies (see for example, Cutter et al (2008), Berkes and Ross (2013), IFRC (2016), UNDRR (2017), NIST (2021)). Our approach is unique in that it is focused on school communities and has been developed through a critical examination of the functions of a school along with the enabling and disabling factors. We followed a participatory approach and gathered the experiences and views of school communities to develop the school resilience framework. The accompanying tool is easy to use by the schools to track their progress as well as by the regional local authorities to make policy decisions for improvements in their region.

6. CONCLUSION

From a disaster resilient infrastructure perspective, there are a number of strategic challenges to the local authorities and stakeholders. To address some of these, this paper has presented a holistic framework for the assessment of schools and the accompanying tools. SAFER structural rapid visual survey tool can enable statistical prioritisation of school buildings for retrofitting and adaptation measures at different geographic scales. The other aspect of the SAFER tool relates to the evaluation of resilience of educational community through fourteen resilience indicators. This can be used by the educational communities for the self-assessment of schools and track their resilience with time. Further, the results of both assessments, structural safety and community resilience, are provided on a map for decision-making at appropriate levels. The capabilities of the SAFER toolbox and the adaptive pathways for school infrastructure resilience it offers have been illustrated through application to two schools in different countries. Such an informed decision-making and timely action on resilience-building measures can greatly mitigate the social and financial impact of future earthquake events.

7. ACKNOWLEDGEMENT

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