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Research Paper

Lifeline infrastructure and the UN disaster resilience scorecard

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ABSTRACT

The 2015 Nepal M 7.8 Earthquake and M 7.2 Aftershock caused catastrophic damage across a large area of strong shaking and impacting the entire nation. This paper presents best practices in evaluating core community functions in need, and planning for rapid and resilient recovery, building back better. Several tools and methods are explained including the concept of lifeline infrastructure resilience and performance goals under the 2015 United States (US) National Institute for Standards and Technology (NIST) Community Resilience Planning Guide; use of HazusMH loss modeling software adapted to measure losses avoided from modern hazard resistant building code provisions; and a framework for success using the new United Nations Disaster Resilience Scorecard, developed by IBM and AECOM, now piloted in over 30 cities since 2014 rollout. The utilization of the UNISDR scorecard for Kathmandu indicates the applicability of these techniques in evaluating the resilience of key infrastructure and institutional facilities, and how they can be an effective tool in planning and Disaster Risk Reduction.

1. Introduction

The 7.8Mw April 25, 2015 Nepal Earthquake caused strong shaking propagating over vast areas of Nepal's mountain terrain (Fig. 1). Loss and damage of structures, landslides and corresponding failure of roads, foot trails, utilities and hydropower impacted the entire society. This cut off service of national lifelines to local markets and to Kathmandu stalling the economy. Impacts spanned health, education, transportation and agriculture.

The ability of survivors to cope and begin recovery with little to no resources reflects an inherent resilience of Nepal's rugged independent mountain culture. However protracted delays in recover from limited governance capacity highlight need for a more effective integrated recovery. The October 8, 2015 Consequences of 2015 Nepal Earthquake & Integrated Post-Disaster Management workshop (C2015NEIPDM) agenda was based upon the observed acute loss drivers. This paper

Fig. 1. Building collapse dust during Nepal Earthquake (photo Guillaume Prudent-Richard, AECOM).

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presents best practices for resilient recovery introducing five framework models, recently developed in the US, and relevant to Nepal:

- Infrastructure Resilience Model of the American Society of Civil Engineers (ASCE)
- The National Disaster Recovery Framework (NDRF) of the US Federal Emergency Management Agency (FEMA),
- The Community Resilience Planning Guide, National Institute of Standards and Technology
- FEMA HazusMH loss modeling software,
- The UN Disaster Resilience Scorecard.

These five new frameworks can be coordinated in a logical progression towards resilience as summarized below:

- Assessing the losses in terms local and regional critical lifeline infrastructure systems (CISLC) including critical facilities (ASCE, 2015);
- Evaluating rapid recovery support functions (RSF) (FEMA, 2016);
- Incorporating CISLC and RSF concepts into holistic community resilience planning by community core functions with social and operational capacity development which the infrastructure serves (NIST, 2016);
- Quantifying benefits of hazard resilient building codes with Hazus losses avoided (LA) modeling of economic and insurance gains via average annualized losses (UNISDR, 2016);
- Establishing an integrated baseline by screening and scoring Ten Essentials of UN Disaster Resilience Scorecard (AECOM and IBM, 2015).

The collective understanding of local needs driving whole community resilience and effective overall recovery investment derived by these complementary evaluations will help officials, planners and communities compare and prioritize specific findings the Post Disaster Needs Assessment (PDNA). To illustrate this, first, the new ASCE lifeline infrastructure resilience engineering model and the FEMA NDRF is discussed, followed by Hazus. The engineering focused NIST Community Planning Guidance, and last the UN scorecard.

2. Lifeline Infrastructure Resilience

Lifeline infrastructure (water, power, transport, communications, etc.) is that most vital to allow a community to sustain only most critical functions and services following a catastrophic disaster. ASCE pioneered over two decades ago lifeline engineering concepts now adopted by many institutions and government agencies. In 2015 ASCE launched the Infrastructure Resilience Division (IRD) to improve the resilience of civil infrastructure and lifeline systems with tools and resources. The lifeline approach fosters lower cost development of more robust physical systems, operational enhancements and integrating infrastructure planning and resources to cope with impacts, reduce losses and expedite recovery.

Combining engineering and community planning can yield more resilient systems, institutions, families and citizens. Lifeline infrastructure engineering allows focusing scarce physical investment resources on the most essential community functions, and brings awareness to the diverse stakeholders of needs and capabilities, fostering collaborative working relationships. IRD developed an infrastructure resilience model (**Fig. 2**) which identifies roles and relationships of engineering to support community resilience (ASCE, 2015).

Of note is the complex relationship and resilience profile unique to each community for hazard exposure type, lifeline infrastructure sectors supporting core community functions, and optimal time domain within the disaster life cycle to perform physical or operational interventions to achieve resilience via reduced loss and rapid recovery.

The cross cutting themes weave an interface of social, environmental, operational and physical domains, for evaluating primary and cascading consequences, supply chain resilience analysis, business continuity planning as a risk analysis or triple bottom line framework. These predicted outcomes can then be used to establishing risk or loss tolerances, performance goals for core community functions following a disruptive event, and relative prioritization of mitigations, interventions and resilience indicators and risk reduction actions.

3. Community resilience

Six critical community recovery support functions (RSF's) are discussed under the US National Disaster Recovery Framework (NDRF) providing means to collaborate across agencies, jurisdictions and the private sector to efficiently build back better (**Fig. 3**).

Prior to 2012 release of the initial NDRF, objectives for rapid recovery and building back better were not strongly linked in the disaster cycle used to delineate government disaster programs. The NDRF identifies the continuum, and overlap of disaster phases wherein reduction in either recovery time or recovery cost/extent of loss, be it short term disaster related or long term sustainability / climate adaptation related. They can be accomplished to by interventions in any of the phases

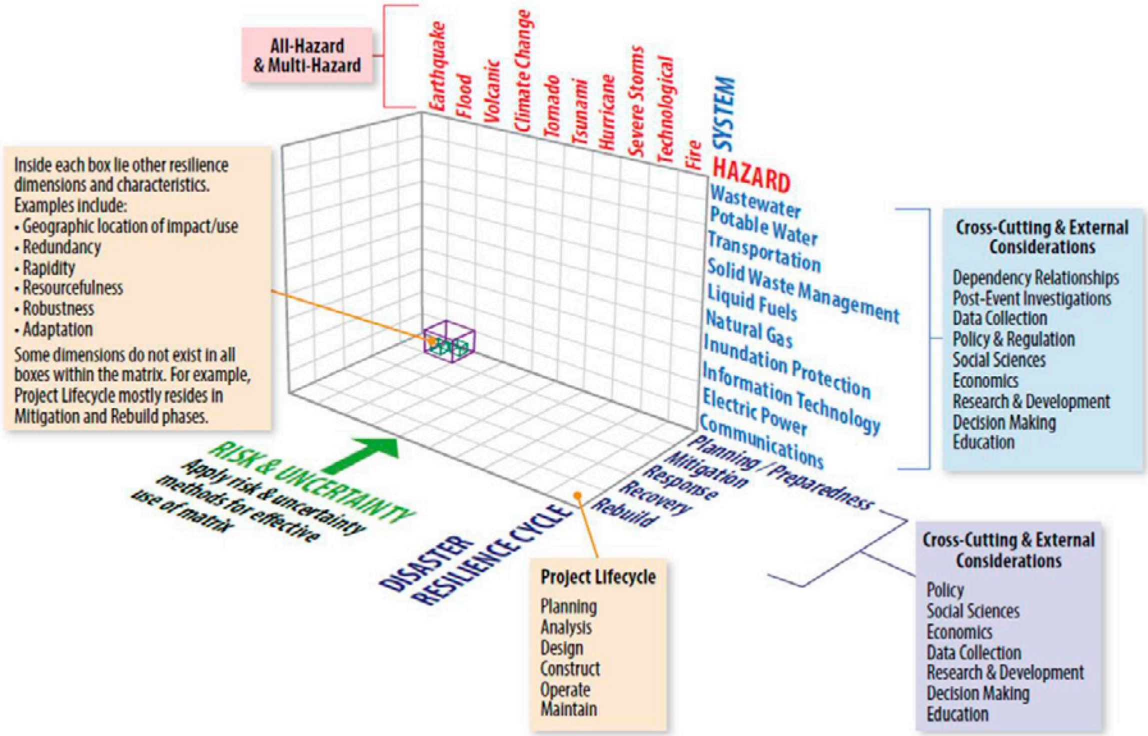


Fig. 2. ASCE Lifeline Infrastructure Resilience Model (ASCE, 2015).

(**Fig. 4**). By definition these effects result in greater resilience, as shown in **Fig. 5** for community resilience guidance (CRG) published by the National Institute of Standards and Technology (NIST, 2016).

Under the NIST CRG, selected outcomes to guide resilience actions and decisions stem from community recovery goals, and then working though each goal, address gaps and goals for supporting infrastructure systems (**Fig. 6**) to provide the 4 R's of resilience: redundancy, robustness (structural strengthening), resourcefulness (adaptive change), or rapid repair schemes to meet the community functional capacity objectives (**Fig. 7**).

Planning can also then effectively extend to metropolitan areas and regional area to allow sharing of resources by mutual aid agreements and predetermined contingency contracts for materials, long lead parts on hand, supplies and reconstruction services.

The role of community resilience engineering is to align core critical infrastructure capabilities with the core community functions. It is conceptualized by disaster consequence screening and socializing scenarios across resilience working groups and recovery exercises.

A key outcome of the collaborations is the need for building what back better and who's going to pay for it? Or building better in the first place for all new construction. And deciding which investments or renovations produce the greatest risk reduction for the cost. And which can be executed quickly with the least financial burden.

In a disaster recovery setting, the combination of planning while assessing damage has been coin analogous to "repairing the ship while sailing". Each of the six recovery support functions represent essential communities needs which begin with "triage", then

Fig. 3. Recovery Support Functions (FEMA, 2016).

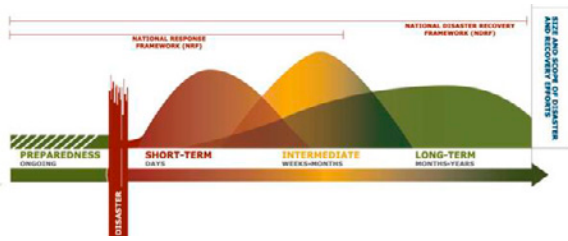


Fig. 4. Recovery Phases (FEMA, 2016).

Fig. 5. Community Resilience Curves (NIST 2016).

INFRASTRUCTURE	RECOVERY TIME								
Critical Facilities	Days 0	Days 1	Days 1-3	Wks 1-4	Wks 4-8	Wks 8-12	Mos 4	Mos 4-24	Mos 24+
Buildings	90%							X	
Transportation		90%	X						
Energy		90%	X						
Water			90%		X				
Wastewater				90%				X	
Communication		90%		X					

🟩 Where we want to be
🟦 Where we are now

Fig. 6. Infrastructure Recovery Goals (NIST, 2016).

TARGET STATES OF RECOVERY FOR SAN FRANCISCO'S BUILDINGS AND INFRASTRUCTURE

INFRASTRUCTURE CLUSTER FACILITIES	Event occurs	Phase 1 Hours			Phase 2 Days		Phase 3 Months		
		4	24	72	30	60	4	36	36+
HOUSING AND NEIGBORHOOD INFRASTRUCTURE									
Essential city service facilities							X		
Schools							X		
Medical provider offices								X	
90% reighborhood retail services									X
95% of all utilities								X	
90% roads and highways						X			
90% transit						X			
90% railroads							X		
Airport for commercial traffic					X				
95% transit							X		

Fig. 7. Example Community Goals (NIST, 2016).

advance to some sense of minimum normalcy such as children in schools, foot markets reopening, etc., followed by final restoration and improved reconstruction.

By beginning the recovery with community RSF's already identified and having worked together on goals, the decisions and execution can be greatly increased. As of 2015, RSFs had been applied in approximately 20 disasters across the US. Each city has its own risk profile, objectives and stakeholders to understand and initiate a functional collaboration. Disaster will not take notice of the level of preparation of a community so planners and emergency officials can manage the consequences and risks before the disaster or they will demand full attention after. This requires breaking down "silo" organizations, bringing together planners, design engineers, building officials, security professionals, emergency personnel, insurers, economists and private sector organization-both infrastructure and community business based.

Funding can be a severe challenge for maintaining status quo let alone any added resilience measures, so the screening of what is most critical and developing a risk culture to raise perceptions and buy-in to the most essential items will allow for doing more with less when everyone realized you are in the same boat. A champion often in the form of a Chief Resilience Officer serves as a facilitator for the collective process.

Common community resilience efforts can apply to prioritizing between RSF performance goals, decisions about where to build (zoning) and how to build (such as adopting minimum hazard resilient provisions in modern international building code). Where warranted in many cases adopting higher standards than the code provisions is needed to attain critical or high yield risk reduction performance objectives in specific areas.

Crucial collaboration also plays out in decisions about funding physical vs. operational and organizational capacity and resilience measures, when different approaches can reach common life safety objectives, such as flood evacuation versus building or siting retrofit. It is not insignificant the monitoring and warning systems for people are a keystone of the Sendai framework (UNISDR, 2015).

In sorting through the noise of politics, there is no better tool than scientific engineering risk based quantification of alternatives and their performance and costs. This can be frames in terms of triple bottom line assessments, and new related method for recognizing greater yields and justification for monetization such as natural capital and sustainable return on investment.

4. HAZUS MH Losses Avoided Modeling

The need for developing method of quantifying resilience actions and their benefits is also a priority of the US policy underlying NDRF and the NIST CRF. Rapid low cost GIS hazard and infrastructure modeling tools can provide profiling of opportunities to reduce or avoid losses, and frame those benefits in terms of insurance risk based criteria such as average annualized losses (AAL) to support financial planning and decision tradeoffs. Tools for monitoring, evaluation and evacuation options are included scalable to community, metro center, regional and national needs.

An example of ASCE and NIST resilience "standards based" approach for the built environment was applied with HazusMH Loss Modeling software (FEMA, 2014), for the dominant wind, flood and seismic hazards. By measuring and modeling with Hazus in Building Code Adoption Losses Avoided Studies (LAS), benefits due to modern building code adoption can be show as dollars saved by risk reduction. With this information, communities can be incentivized by recognizing the benefit they are already realizing and which will grow into the future for their resilience investments in buildings and infrastructure. The methodology developed by AECOM for FEMA incorporates building and hazard data collection summarized in **Fig. 8** (UNISDR, 2016).

To demonstrate the effectiveness of the concept and method, AECOM performed a demonstration study modeling all buildings in a given region, by type and building code version in Hazus and assigning modern building code hazard provisions to each structure where appropriate and comparing losses with an without those provisions. The intersection of population and building growth in the past 15 years nationwide is shown for the entire country against mapped relative seismic hazards exposure contours (**Fig. 9**). construction with and without modern building code provisions between the years 2000 -2015 is shown in **Fig. 10**, with a breakdown by State. These same kinds of benefits can be realized by Nepal from the earthquake recovery investments to build back better for reduced building losses during future earthquakes, noting it may take decades in both the US and Nepal to migrate an entire building inventory to modern code provisions. But even after a decade the risk can be appreciably reduced.

– **Hazard maps:** Flood, wind, seismic
– **Building code versions:** Identify I-Code version used for construction and code used prior to I-Code
– **General building characteristics:** General assessor data
– **Hazard-specific loss parameters:** Flood, wind, and seismic structural and non-structural features

Fig. 8. Data Needed for a Hazus Building Code LAS.

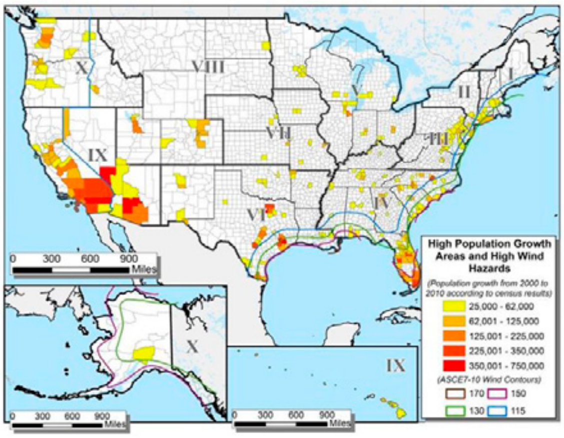
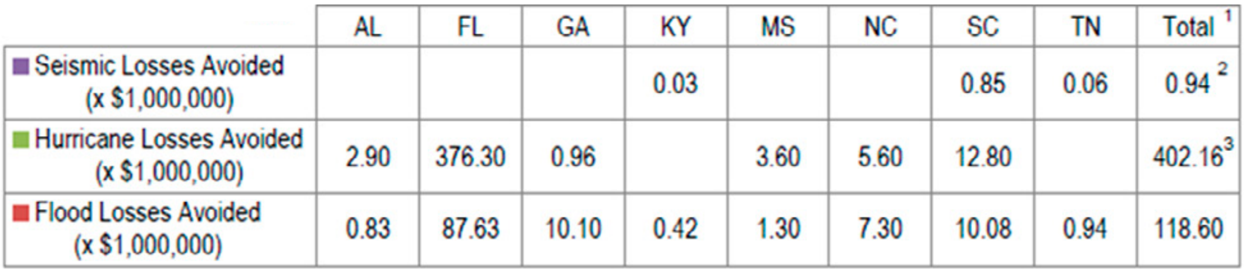


Fig. 9. Example GIS building data overlay with hazard map for the US (UNISDR 2016).

5. The UN Disaster Resilience Scorecard

The UN Disaster Resilience Scorecard (ref. AECOM & IBM, 2015) provides a holistic basis for planning and organizing institutional and social capacity building, emergency planning, capital resource allocation and investment. Ten essential of resilience with scoring criteria have been organized and refined by pilot studies in over two dozen cities around the globe to provide sharing of examples and lessons learn (**Figs. 11-12**).

The scoring and needs assessments are introspective not competitive between cities, aimed to drive towards



	AL	FL	GA	KY	MS	NC	SC	TN	Total [1]
🟪 Seismic Losses Avoided (x $1,000,000)				0.03			0.85	0.06	0.94 [2]
🟩 Hurricane Losses Avoided (x $1,000,000)	2.90	376.30	0.96		3.60	5.60	12.80		402.16 [3]
🟥 Flood Losses Avoided (x $1,000,000)	0.83	87.63	10.10	0.42	1.30	7.30	10.08	0.94	118.60

Fig. 10. Example results of building code adoption LAS (UNISDR 2016).

highest impact actions available to each. It provides a transparent process to demonstrate progress on a systematic path to resilience, compliant with the Sendai framework and the Global Goals for Sustainable Development launched last week. It orients communities to align resources with needs of people first and foremost.

5.1 An Assessment for Kathmandu

Following the Nepal 2015 Earthquake, team of AECOM engineers undertook a series of field missions to understand the impact of the earthquake on key infrastructure facilities (Whitworth et al., 2016). The assessment enabled a preliminary assessment for Kathmandu focused on 4 of the ten essentials; Nos. 2, 4, 6 and 8 (**Fig. 12**).

The assessment indicated that although a sound understanding of natural hazards linked to earthquakes, landslides and monsoons exist, with the establishment of the National Society of Earthquake Technology; the development of seismic design codes. There is little evidence for detailed risk assessments undertaken and limited assessment and mitigation of key lifeline infrastructure (**Fig. 13**). Furthermore, within the last 10 years Kathmandu has undergone rapid expansion, leading to building constructed within a variety of terrain that is susceptible to both earthquakes and monsoon flooding (**Fig. 14**).

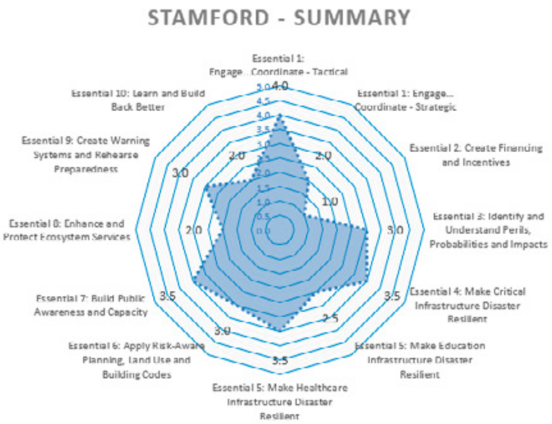


Fig. 11. Scorecard results example, Stamford, CT.

Both Schools and Hospitals (**Fig.15**) were severely affected, despite many being constructed to design code. However, many of the hospitals were able to function with reduced capacity, due to back up facilities and had implemented effectively the Disaster Preparedness plans.

Over 8000 schools were either damaged or destroyed and were unable to function as a school or undertake a secondary role in the immediate aftermath of the earthquake i.e. shelters. Despite this, within weeks of the earthquake, temporary schools had been constructed and in many areas schools were able to function.

Based on preliminary assessment the UNISDR assessment indicates that Kathmandu has a low score of between 1 and 2. Of particular note is the susceptibility of critical infrastructure to natural hazards including many

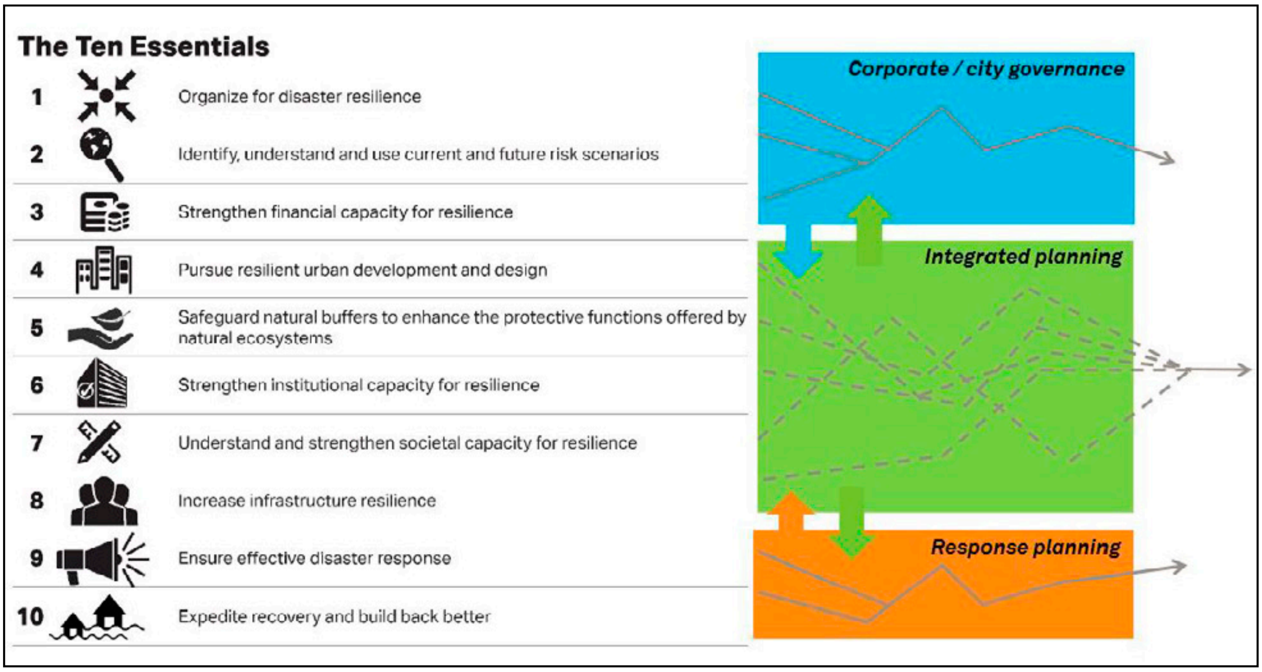


Fig. 12. UN Disaster Resilience 10 Essentials.

Fig. 13. (a) Building on soft lake deposits with Kathmandu (b) and (c) examples of collapsed buildings within Kathmandu in vicinity to **Fig. 13(a)**.

essential road routes and the impact of the earthquake on schools and hospitals despite an earthquake design code being in use in Nepal. Many of the fundamentals to enable Kathmandu to be a resilient city exists, including an understanding of the magnitude and frequency of natural hazards, earthquake design codes and a desire following the earthquake to build back better.

In the predominantly rural area, it is forcing a protracted recovery and a relatively low resilience score. This can be greatly improved with updated building code provisions, training of local designers and construction workers in strengthened building methods, and institutional capacity and transparency.

The UN Disaster Resilience Scorecard will continue to be disseminated to communities for use and enhancement, including as a basis for evaluation DRR impact to the UN Global Goals for Sustainable Development and UN Risk Sensitive Investment Program aimed at better prioritizing DRM strategies, risk metrics, training, and insuring resilience (UNISDR, 2015).

Fig. 14. Landslide affecting key route from Nepal to China.

Fig. 15. (a) Soft story collapse of school in Chautara (b) and (c) structural damage to hospitals in Kathmandu.

6. Conclusion

The five new frameworks developed in the US presented in the paper provide a logical progression toward community disaster resilience, incorporating planning functions, detailed infrastructure engineering, modeling of financial incentives and most importantly socializing of a common vision. By organizing these tools around the lifeline infrastructure model and measuring whole community needs with the UN Disaster Resilience Scorecard, that the resulting scientific engineering based quantification of risk reduction measures and benefits ca be applied to achieve common resilience goals - to do more with less, shaped by improved public risk perceptions, tolerances and collaboration. To start in Nepal they can be incorporated into existing regional seismic planning functions quite simply.

Acknowledgements

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