

Measures to improve resilience and manage poverty in developing countries

[Gian Paolo Cimellaro, Melissa De Iuliis, Dongjun Lee]

Abstract— Developing countries are more vulnerable to natural hazards because typically they are located in extended areas largely affected by flooding, seismicity, land sliding, etc. and their economic, social, political, and cultural conditions are not adequate. Furthermore, high rapid population growth, rapid urbanization process and poverty contribute to poorly built structures, which are designed by non-expert workers without technical skills on construction techniques and seismic engineering. Buildings in developing countries are designed with adobe and rammed earth; they have low strength and fragile behavior of their walls making their inhabitants live under risks. Affordable housing is a major challenge in most areas in developing world. Existing engineering solutions adopted in developed countries are expensive and technically demanding in these areas. Further, the number of studies related to developing communities is rather limited. This has led researchers to discover simple and cost-effective solutions which help in reducing cost construction and reinforcing structures against multiple hazards through the use of locally available, natural, and renewable materials that would improve the durability of structural components achieving affordable housing. The objective of this paper is to investigate existing disaster prevention strategies and cost-efficient techniques to improve the resilience of developing urban systems against natural disasters.

Keywords— Resilience, Developing Countries, Vulnerability, Cost-efficient technologies, Durability

I. Introduction

Natural disasters (e.g., earthquakes, floods, hurricanes) occur worldwide but they have a considerable impact in developing countries (also called Third World Countries), such as India, China, Mexico or Bangladesh (Fig. 1). Most of develop-ing countries are placed in areas mainly affected by natural hazards.

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For instance, Asian and Latin American cities are the most vulnerable to flood-related hazards sharing a high concentration of typhoons and cyclones since they are

located on a river bank or sea cost [1]. Moreover, in these regions the city population is ever-increasing. Slums or “invisible” zones in poor countries are growing faster than the planned parts [2], placing the population at high risk during catastrophic events.

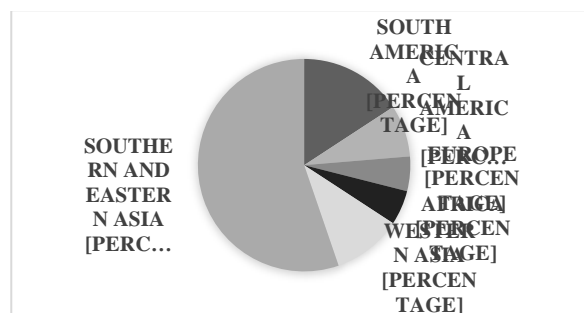


Figure 1. Distribution of extreme natural disasters in developing countries from 1970 onwards.

Over the past two decades, more than 1.35 million people died in about 7,000 natural disasters and 90% of those casualties occurred in developing countries. Table 1 lists the extreme natural events that happened from 1970 onwards in developing countries. For instance, Haiti during the devastating earthquake in 2010 lost more lives than any other country between 1996 and 2015. As pointed out by ex UN chief Ban Ki-Moon during the 2016 International day for disaster risk reduction, high-income countries might suffer from huge economic losses but in low-income countries many more people die because of natural disasters. On average the death toll in low-income countries is five times greater than in high-income countries. Former head of UN office for disaster risk reduction (UNDRR) Robert Glasser compared 2008 Cyclone Nargis, which caused 138,000 victims in Myanmar, to 2010 Cyclone Yasi, which caused zero casualties in Australia despite being in the top ten of most powerful cyclones. Earthquakes and tsunamis were the biggest killers in the past 20 years, followed closely by climate change related events, which are increasing rapidly. Hundreds of millions of people are at risk as they live in dangerous areas such as marginal lands, unstable hills and coastlines. The occurrence of disasters associated with natural hazards in developing countries is not only due to geographical location, but also due to the vulnerability of their systems. Economic and social systems in these countries contribute to poor standards of buildings, designed by using readily available materials at little or no cost, as bamboo and wooden materials. Furthermore, the high vulnerability of buildings is due to inadequate construction techniques, lack of technical assistance or quality control, that are the main culprits for living in non-durable structures and suffering from housing unaffordability.

To improve housing affordability, it is important to adapt and develop alternative housing construction systems according to local conditions, minimizing the use of costly materials without affecting the quality of construction. That is, by using appropriate cost-effective and 'sustainable' materials and innovative technologies that would improve the durability of building components, is it possible to achieve affordable housing. Bredenoord [3] discusses three types of sustainability: technical sustainability (durability), climate friendly sustainability, and social sustain-ability.

2010 Haiti earthquake	Haiti	January 10, 2010	300,000
Typhoon Bopha	Philippines	December 4-5, 2012	1,901
Typhoon Haiyan	Philippines, Vietnam, China	November 3-4, 2013	6,340
2014 Ludian earthquake	China	August 3, 2014	729
2015 Nepal earthquake	Nepal, India	April 25, 2015	8,964
2016 Ecuador earthquake	Ecuador	April 16, 2016	676
2018 Suiawesi earthquake and tsunami	Indonesia	September 28, 2018	4,340

Table 1. Extreme natural events in developing countries from 1970 onwards

Event	Location	Date	Death toll (estimate)
1970 Ancash earthquake	Peru	May 31, 1970	70,000
Hanoi and Red River Delta flood	North Vietnam	1971	100,00
Typhoon Nina	China	August 7, 1975	229,000
1976 Tangshan earthquake	China	July 28, 1976	242,769 - 655,000
Hurricane David	Dominican Republic, Dominica	August 15 - September 8, 1979	2,069
1980 El Asnam earthquake	Algeria	October 10, 1980	5,000
1981 Golbaf earthquake	Iran	June 11, 1981	3,000
El Chichon (Volcanic eruption)	Mexico	1982	3,500
1983 Erzurum earthquake	Turkey	October 30, 1983	1,342
Typhoon Ike	Philippines	August 26 - September 6, 1984	1,474
Armero tragedy (Volcanic eruption)	Colombia	November 14, 1985	23,000
Lake Nyos disaster (Limnic eruption)	Cameroon	August 21, 1986	1,746
1987 Ecuador earthquakes	Ecuador	March 6, 1987	5,000
1988 Armenian earthquake	Armenia	December 7, 1988	25,000
Typhoon Gay	Thailand, India	November 1-10, 1989	1,036
1990 Manjil - Rudbar earthquake	Iran	June 21m 1990	50,000
1992 Flores earthquake and tsunami	Indonesia	December 12, 1992	2,500
1993 Latur earthquake	India	September 9, 1993	9,748
1994 Paez river earthquake	Colombia	June 6, 1994	1,100
1996 Andhra Pradesh cyclone	India	November 4 - 7, 1996	1,007
Tropical Storm Linda	Vietnam	November 1-9, 1997	3,123
Hurricane Mitch	Honduras, Nicaragua, El Salvador, Guatemala, Belize, Mexico	October 22-November 9, 1998	11,374
1999 Izmit earthquake	Turkey	August 17, 1999	17,127
Vargas tragedy	Venezuela	1999	10,000 - 30,000
2001 Gujarat earthquake	India	January 26, 2001	20,085
2004 Indian Ocean earthquake and tsunami	Sumatra, Indonesia	December 26, 2004	227,898
2005 Kashmir earthquake	India, Pakistan	October 8, 2005	87,351
2006 Yogyakarta earthquake	Indonesia	May 26, 2006	5,782
2008 Sichuan earthquake	China	May 12, 2008	87,587
2009 Sumatra earthquake	Indonesia	September 30, 2009	1,115

Nowadays there are plenty of engineering solutions that could mitigate or even eliminate the risk of such numbers of deaths. Some of them are clearly not afford-able for developing countries, but research has shown a number of interventions that are highly cost effective. However, political issues and corruption have been hampering the implementation and execution of such beneficial measures. Often times monetary resources are badly administrated and even supplies donated from developed countries are not properly utilized [4]. The selection of affordable and low-cost construction solutions through locally and durable materials is therefore the only option to provide safety to people in developing countries.

The purpose of this paper is to present existing effective solutions for developing construction procedures to achieve housing affordability and for improving the resilience of developing urban systems against multiple hazards.

II. An Approach to Community Resilience

Measuring resilience is one of the most challenging tasks due to the complexity involved in the process. The concept of resilience has different definitions since it has been studied, reviewed, and applied in several fields (e.g. ecology, economy, engineering) with different meanings. In engineering, the concept of resilience is "the ability of social units (e.g. organizations, communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways to minimize social disruption and mitigate the effects of further earth-quakes" [5, 6]. Several solutions for measuring resilience are available in the literature [7-9]. By looking at the existing measurements framework, the resilience can be calculated according to the spatial level (e.g. individual building, region, state, community) through qualitative and quantitative approaches. PEOPLES framework is an example of quantitative framework for designing and measuring the resilience of communities [10]. The acronym "PEOPLES" combines seven dimensions of community: Population; Environment; Organized government services; Physical infrastructure; Lifestyle; Economic; and Social capital. The framework allows measuring the community resilience by evaluating the performance of the infrastructures and their interdependency.

During the United Nations World Conference on Disaster Reduction in 2005 in Japan, the Hyogo Framework for Action (HFA) was adopted [11] by associating the concept of resilience with vulnerability and adaptive capacity as the underlying approach in reducing disaster risks. The Hyogo Framework for Action, intended to address 'Building the

Resilience of Nations and Communities', identified the following action priorities: 1) Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation; 2) Identify, assess and monitor disaster risks and enhance early warning; 3) Use knowledge, innovation and education to build a culture of safety and resilience at all levels; 4) Reduce the underlying risk factors; and 5) Strengthen disaster preparedness for effective response at all levels [11]. An evolution of the risk assessment concept was introduced by Kammouh et al. [12]. In their approach resilience has been estimated at the state level based on the HFA assigning a score between 0 and 100. Kwasinski et al. [9] proposed a hierarchical framework for evaluating resilience at the community level through community dimensions. The abovementioned resilience frameworks are only few methods that have been investigated in literature to reduce the vulnerability and increase the resilience of communities.

However, disaster risk reduction and resilience evaluation have been understudied in developing countries due to local, political and cultural issues. Thus, affordable solutions and low-cost technologies have been developed to improve the durability of structures in poor countries. The following section aims at describing the existing measures that can be adopted in developing countries.

III. Measures to Improve Resilience And Manage Poverty in Developing Countries

To improve resilience in developing countries new approaches should be investigated and proposed. Most of the frameworks that can be found in the literature were indeed derived having in mind the structure of modern communities. There-fore, they cannot be applied as they are to developing communities where for in-stance some infrastructures are partially or totally missing. The first step to more resilient communities should focus on better construction techniques which allow to reduce the number of collapses and casualties. The objective is to increase the durability of these structures so that they can withstand the natural hazards they are exposed to. By increasing the durability of residential and strategic buildings, housing can be overall more affordable as a structure does not need to be rebuilt every time some sort of hazard happens. The following are affordable and effective measures that can be successful at increasing housing durability and improving resilience in developing countries.

A. Policies and Regulations

Early warning systems and better preparedness can definitely help to improve the situation as demonstrated by recent events like 2016 Cyclone Winston in Fiji where actions taken by the authorities helped to avoid a catastrophe in terms of casualties. Other virtuous examples can be found in India and Nepal where some communities were given housing designed to withstand earthquakes and cyclones, or in Nigeria where the health ministry was successful at stopping the spread of Ebola.

In his work Kenny [13] suggests the adoption of approaches based on simple disaster risk regulations for

structures at risk that can be supervised by non-experts aiming at maximum transparency. For private and small buildings, the best strategy is to educate private owners instead of regulating, while engineers and urban planners can focus on strategic and public buildings. In situations where there is low interest for risk mitigation and governance is poor, US or EU regulations are not applicable. Simple approaches to risk mitigation need to be implemented and applied. There has been valuable research regarding simple construction practices that can significantly reduce the risk of collapse, such as openings size and placement, wall width and height. Such simple measures reduce the burden on policy agencies and allow for a straightforward review of the work done by regulators.

B. Base isolation

As demonstrated by many natural disasters in the past few years, many victims are caused by the collapse of poorly constructed buildings. These unfortunate consequences are likely to happen even in areas struck by moderate intensity events. Considering the seismic hazard, research has shown how techniques such as base isolation can be redesigned to reduce costs and thus be utilized to build more resilient structures or retrofit existing ones. A possible improvement plan could be starting from retrofitting existing strategic buildings such as schools and hospitals. Typically, the limits of traditional base isolation systems are excessive cost and weight. In his research, Kelly [1] has successfully investigated an alternative low-cost design of a new base isolation element. The underlying idea consists of replacing steel reinforcing plates that are commonly found in rubber bearing isolators with fiber reinforcements. The high cost of isolators is indeed mainly due to the industrial realization of steel plates which need a number of procedures to be correctly prepared and assembled together with the rubber sheets. Fiber reinforced materials seem to represent a viable option since they have elastic stiffness comparable to steel but much lighter weight. Another innovative aspect proposed by Kelly [1] concerns the shape of the devices. Isolators are all circular or square shaped. A rectangular shape would bring clear advantages when applied to buildings with walls as main structural elements such as unreinforced masonry and concrete blocks structures, which are typical examples of construction techniques adopted in developing countries. Therefore, strip shaped fiber reinforced isolators allow for a cheaper manufacturing process and application. In addition, they are lightweight and can be cut with standard saws rather than special saws required to cut steel reinforced isolators. As far as the vertical stiffness is concerned, it was assumed a linear elastic behavior with incompressibility considering also the extensional flexibility of the reinforcement. Tests on several fiber reinforced rectangular rubber isolators showed impressive performances, despite the vertical and horizontal stiffnesses were inferior with respect to equivalent steel reinforced devices.

An additional step in reducing the cost of base isolators was analyzed by Calabrese et al. [2] who validated the possible use of recycled rubber fiber reinforced bearings to improve seismic performances of houses in developing countries. Natural rubber can be effectively replaced by recycled compounds coming from tires, industrial leftovers, rubber chips, etc. [3, 4].

Morales, Filiatrault [5] proposed the Recycled Tire Bearing (RTB) system designed to isolate critical rooms in health care facilities such as emergency rooms and recovery rooms. The system consists of recycled tires cut through their diameter and placed between the structural slab and a newly designed floor surface. In this system each tire is compressed under the gravity load of the floor surface. The RTB system has relatively high damping and low horizontal effective stiffness, which reduces the transmission of floor acceleration to non-structural elements.

A low-cost seismic isolation strategy for developing countries was also proposed by Tsiavos, Alexander [6]. Their system consists of a sand-rubber foundation layer on which the structure should be designed to withstand the earthquake acceleration. Depending on the earthquake intensity, three different behaviors have been studied. For low intensity, sliding between the sand-rubber foundation layer and the structure is not activated and the structure is designed to face the seismic forces through simple measures. In case of moderate intensity, the foundation will shear within the soil rubber layer. Finally, for high intensity, sliding is expected.

C. Reinforcement techniques for earthen buildings

In many developing countries buildings are built through poor construction technologies and readily available materials. In these countries such constructions are not able to withstand severe earthquakes and in most cases they collapse. During the last three decades, new solutions for improving the seismic performance of earthen buildings have been found [7]. The alternatives of seismic reinforcements are described below:

Internal cane mesh reinforcement. Vertical cane rods anchored to a concrete foundation and placed inside the adobe wall have been used for the reinforcement. The reinforcement system consists of horizontal layers of crushed canes that are placed every few adobe rows and tied to the vertical cane reinforcement. Finally, the internal cane mesh is tied to a wooden crown beam.

External wire mesh reinforcement. The external wire mesh reinforcement technique consists of nailing wire mesh bands against adobe walls and then covering them with cement mortar. The external mesh is placed in horizontal and vertical strips.

External polymer mesh reinforcement. Bands of polymer mesh are tied to both sides of the walls with plastic string threaded through the walls. The bands of plastic mesh are located in the regions where most damages are expected on the adobe walls. That is, the amount of damage increases as the quantity of polymer mesh reinforcement decreases.

D. Low-cost bamboo frames

The mechanical properties of bamboo are well known in construction traditions since it is a low-cost building material, available worldwide, flexible, durable and lightweight [8]. The use of bamboo as a natural construction material is regulated in several countries, such as Colombia and Peru [9-11]. Three low-cost solutions for bamboo joints have been implemented: (i) joints with steel nails, bolts and steel plates [12, 13]; (ii) steel nails and bolts with plywood

plates [14, 15]; (iii) wooden bolts, canapé rods plywood plates [16, 17]. In the first typology of joint a single bamboo cane is used with a wooden cylinder and connected to a metal plate. The lower extremity of each rod is connected by three bolts. The second joint is made by plywood plates used in place of steel plates and the internal part of bamboo cane is filled with wooden sticks instead of a single wooden cylinder. The third solution shows a further simplification. The joint consists of a couple of bamboo rods connected by wooden pins and it is transversely strengthened by canapé ropes. The three joints lead to an increasing ductility due to a progressive weakening of joints and simplicity in execution. Also, bamboo has a durability of 30-35 years if it is treated well and is under the cover of a roof.

A large-scale program is to be found in Ecuador, where around 265,000 traditional bamboo homes have been built. The new housing models combine high-strength and durability-treated wood. Another bamboo housing model was developed by Arup by using timber and locally grown cane [18]. Even though the bamboo is sustainable, and a bamboo house is earthquake resistant, the use of this resource as a construction material is still limited partly due to political reasons.

E. Confined masonry

Porst, Brzev [19] proposed confined masonry as construction technology in developing countries, in particular in India. Confined masonry is a composite wall system that includes masonry walls and surrounding reinforced concrete elements (i.e. tie-columns and tie-beams). The masonry panel develops a diagonal compression strut when resisting lateral loads and when the masonry has cracked, tie-columns provide ductility before the collapse. Tomažević and Klemenc [20] illustrate that the ductility of confined versus unconfined masonry increases, thus building occupants have more time to evacuate during an earthquake. The resilience of confined masonry is quantified relating to its wall density. In this work, a simplified analysis is also described to determine the required wall density. Finally, confined masonry buildings are a good solution in places like India, where steel and cement are the costliest construction materials.

F. Wing walls installed to existing columns

A practical method for strengthening and repairing reinforced concrete beam-column joints in developing countries was investigated by Li, Sanada [21]. This strategy has been mainly designed for RC buildings that have no horizontal reinforcement in beam-column joint, as they were designed according to older codes or built by people without deep technical knowledge. Installing RC wing walls beside existing columns is a simple and practical solution of strengthening buildings in poor countries, considering their economic situation and the technical level. Results show that the installation of RC wing walls effectively improves the seismic performance of existing frames, leading to a ductile beam yielding mechanism. Finally, this technology can be also applied to repair seismic damaged building.

G. Low-cost housing systems

The concept of low-cost housing system in developing countries has aroused great attention in engineer community due to the appropriate use of local materials, skills and technology in designing structures without sacrificing the performance of the structures.

Tam [22] found that the cost-effective and alternative construction technologies can protect the environment following the prevailing building codes. In this work alternative construction solutions are described. Arch foundation is used in walls that are supported on brick or stone masonry; rat trap bond is applied as an alternative brick bonding system. This technology does not require plastering of the outside face and air gaps within the wall make the house thermally comfortable. Finally, a filler slab roofing system is proposed. This technique is based on the principle that for roofs which are simply supported, the upper part of the slab is subjected to compressive forces while the lower part to tensile forces.

Ganiron Jr and Almarwae [23] introduced the use of Modular Housing System as innovative system for economic houses. The prefabricated components are brought to the site and erected using building block type construction. The building process is never delayed by missing materials or curing time and it can be completed for 30 up to 45 working days. Comparing to the traditionally build house using traditional materials, the modular house shows a lower total cost of the project [24]. Advantages of prefabricated components are sound insulation, durability, finishes, design, fire resistant, rapidity in construction, material cost savings, and environment contribution.

The use of interlocking blocks of recycled materials were also proposed for housing systems in developing countries [18]. Interlocking bricks or buildings blocks have a good insulation value that the common concrete blocks. Further, the blocks can be developed in different shapes and sizes and they can even be reused in another buildings. In Haiti, for instance, the building blocks are designed by converting debris into concrete blocks known as 'Q-bricks' for the houses that are earthquake and hurricane resistant. Natural disasters victims can quickly rebuild their houses and communities through this technical process [25]. Two raw materials can be also used for buildings blocks: recycled plastic in the form of polypropylene and rice husks from rice cultivation [18]. That is, rice husks can be used as a building material, insulation material or biofuel after protecting the rice.

IV. Conclusions

Recent natural disasters events have demonstrated the importance of shifting from post-disaster emergency to pre-disaster mitigation actions. Their impact is function of the exposure to and the intensity of the natural phenomena (natural vulnerability) and the human vulnerability. Even though a large number of resilience frameworks have been developed for improving the resilience of communities, these approaches are still limited in developing countries due to their economic and political issues.

The challenges to be undertaken involve educational campaigns to make people aware of the seismic risk, cultural

information to adopt construction techniques with local and raw materials, and construction programs.

This work presented some of the existing disaster prevention strategies and cost-efficient solutions that can be successful in limiting the number of casualties due to natural disasters in developing countries. Low-cost and affordable technologies will contribute to improve the construction technique deficit in the most impoverished countries of the world by using locally available materials and simple solutions for earthquake resistant structures. The process of improving construction techniques and performances of the built environment is the first step towards more resilient communities.

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