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Current practice of earthquake engineering in construction industry in Afghanistan and recommendations

Abstract

Earthquakes pose serious threats to life and infrastructure in Afghanistan especially in vulnerable densely populated cities such as Kabul. Active plate boundaries surround Afghanistan on the west, south, and east causing strong ground shakings in many parts of the country. These strong earthquakes often claim lives and cause social and economic losses to the nation. In order to reduce the extent of damage and loss of life during earthquake catastrophes, the effects of earthquake must be properly considered in design and construction of infrastructure including buildings, towers, bridges, dams, tunnels and other engineering structures that are constructed or will be constructed in regions of high seismicity in the country. In addition, parts of the country especially western Afghanistan are seismically inactive. In such regions, design and construction of infrastructure for large earthquakes will result in economic losses and inefficient use of resources. This paper evaluates the reliability and certainty of current practice of seismic design and incorporation of earthquake engineering principles in construction of civil engineering structures in seismically prone parts of Afghanistan.

Factors influencing earthquake engineering practice such as

I. Reliability of seismic design input data or current earthquake hazard map,

II. Proficiency of earthquake engineering practitioners and methods of structural analysis, and

III. Adoption and enforcement of seismic design and construction standards are evaluated.

This paper concluded that the current practice of earth quake engineering in Afghanistan is not adequately reliable and therefore building and other infrastructures are either under-designed or over-designed where both result in sub-standard infrastructure.Under-designed structures threaten lives and cause economic losses during strong earthquakes, while over-designed structures are not economical and have wasted resources. At the end, recommendations are made to enhance the reliability of earthquake engineering practice in the country for producing earthquake tolerant infrastructure that will results in greatly reduced loss of lives and property.

Keywords: Afghanistan, earthquake hazard map, infrastructure, seismic, construction codes and standards, structural analysis

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Introduction

Earthquakes are one of greatest natural hazards to life and infrastructure in the world. History and technical records narrate that they inflicted the deaths of hundreds of thousands of people and caused the destruction of countless cities and villages around the world. Earthquakes' devastations are almost entirely due to the effect of earthquakes on civil engineering structures and the ground supporting them. Therefore, modern societies have decided to minimize earthquakes induced catastrophes by proper application and practice of earthquake engineering fundamentals in the construction of their infrastructures. As to other countries in the world, Earthquakes also pose serious threats to life and infrastructure in Afghanistan. The history of destructive earthquakes in Afghanistan shows that many parts of the country are seismically active regions where triggering of strong earthquakes is also anticipated in the future. The potential for happening strong earthquakes requires that the country's infrastructure have to be designed and constructed by effective application of earthquake engineering principals. The effective application of earthquake engineering principals, in other words the "Current Practice of Earthquake Engineering in Afghanistan" has been studied in this paper in three major areas. These major areas includes the reliability of seismic input data or probabilistic seismic hazard values, proficiency of earthquake engineering practitioner and readily used methods of analysis in engineering designs, and adoption, enforcement of construction codes and standards. This paper concluded that the current practice of earthquake engineering is not efficient and adequate in producing earthquake tolerant infrastructure and hence the resultant infrastructure is highly vulnerable to earthquakes catastrophes. In addition, poorly practiced earthquake engineering has posed serious threats to thousands of lives in the country.

Seismotectonics and history of strong earthquakes in afghanistan

Afghanistan is surrounded on the east, south, and west by active plate boundaries that are associated with deformation, faults, and earthquakes.[1] The country is located on the southern fringe of the Eurasian plate with its seismicity mostly due to the northward movements of Indian plate past eastern Afghanistan at approximately 39 mm/year and Arabian plate past western Afghanistan at approximately 33 mm/year with respect to Eurasian plate. The Afghan and nearby earthquakes are roughly categorized based on their depths as crustal (depths 40 km or less) and mantle (depths greater than 100 km) earthquakes. Crustal earthquakes are concentrated at plate boundaries at east and west of Afghanistan where both Indian plate and Arabian plate subduct under the Eurasian plate. Mantle earthquakes are mostly concentrated beneath the Hindu Kush and Pamirs. The greatest hazard is in and around northeastern Afghanistan characterized by abundant large and small crustal earthquakes and major faults that are comparable to great crustal faults of the world like the San Andreas and North Anatolia faults.[1] Literature contains evidence about ten large seismically active faults in Afghanistan. Only about half of these faults have relatively enough details that warrant additional investigations.[2] These faults are ranked for their potential for generating earthquakes based on surface ruptures, fault offsets, offsets of young volcanic rocks, and alignment of earthquake epicenters. The most seismically active five faults include the Chaman fault, the Darvaz fault, the Hari Rod fault, the Andarab fault, and the Darafshan fault. There are other faults with very little or no evidences presented by the literature about their seismic activities. These faults include the Sarobi fault, the Konar fault, and the Central Badakhshan, Alburz Marmul, and the Panjshir faults. These local and regional faults contributed to triggering strong earthquakes in the Afghanistan. Although some evidence exists for earthquakes in Afghanistan as far back as 2000 B.C[2], Ambraseys et al.,[3] summarized the written history of more than 1300 earthquakes from 734 AD to 2003. They mentioned Persian accounts as their main source of macroseismic information for early periods, and British and French consular records for later periods. Ambraseys et al.[3] provided additional details for few of the more significant earthquakes that caused damages. Some of these events with quantitative information existing about estimated casualties and damages have been summarized in Table 1 below.

Table 1 Significant earthquakes that have details available about their inflicted causalities and damages

Date	Estimated				Causality/ Damages
	Ms	Lat.	Long.	Location	
Jul 6 1505	7.3	34.5	69.1	Kabul	Ramparts of the fort (Bala Hissar), even the walls of gardens destroyed. In particular Paghman (34.58N, 68.95E) was badly affected, all houses there being destroyed and 70 or 80 people were killed, with numerous casualties in nearby towns and villages. The earthquake caused at least 40 km long surface rupture of the Paghman fault.
Jan 22 1832	7.4	36.5	71	Badakhshan	This earthquake and its 21 February aftershock destroyed most of the villages in the Badakhshan, allegedly killing thousands of people. In Kalafgan, Jorm districts forts and houses were destroyed and many lost their lives. From a total population of 310 in three nearby villages 156 were killed. The shock triggered numerous rockfalls, forts and houses were destroyed, and a whole mountain-side fell into the valley. In the Sargulam valley, 72 of a population of 155 perished.
Oct 18 1874	7	35.1	69.2	Kohistan	The densely populated region of Kohestan (35.12N, 69.30E) and the nearby villages of Golbahar (35.14N, 69.30E) and Jabal Saraj (35.13N, 69.24E), were almost totally destroyed with many casualties. Press reported in Kabul (34.53N, 69.13E) that more than 1000 houses were destroyed and many people were killed [Fuchs 1886.485).
1911 Jan 1	7.1	36.5	66.5	Mazar-i- Sharif	In the region of Kalan (35.19N, 69.23E), 60 houses collapsed killing 240 people; in Khnabad (36.68N, 69.11E), 70 houses were destroyed and many people were killed, in Feyzabad (37.12N, 70.56E), houses were ruined caused fatalities. In Kabul (34.53N, 69.13), about 300 houses collapsed killing more than 460 people.
24-Jun-72	6.4	36	69	Takhar Province	During this earthquake, Districts of Khost Fering, Nahrin (36.07N, 69.13E), Ishkimish (36.38N, 69.32E) and smaller settlements within a radius of about 25 km were ruined. A few hundred houses collapsed and about 20 people were killed. Damage to local houses was reported from Baghlan, Pul-i Khumri and Warsaj at epicentral distances of 60 km.
Mar 19 1976	5.5	36.59	67.76	Khulm	This earthquake caused considerable damage in Samangan province, killing about 50 people and ruining more than 1,000 local houses. Rockfalls and slides in the eastern section of the Khulm Gorge buried several vehicles adding to the loss of life.
Dec 16 1982	6.5	36.11	68.98	north Afghanistan	This earthquake destroyed approximately 7,000 houses, killing 450 and injuring 3,000 people in the Baghlan province. The shock caused serious damage and loss of life in the coal mines in the province.
Feb 4 1998	5.9	37.07	70.07	Rustaq (37.12, 69.82)	2,300 people killed, 800 injured and 8,100 houses destroyed, due to this destructive earthquake in north-east Afghanistan. The shock making 8,000 homeless. The earthquake triggered extensive landslides which added to the damage, killing more than 6,000 livestock.
May 30 1998	6.5	37.07	70.09	Rustaq area	The shock killed about 4,000 people, injuring many thousands in the districts of Badakhshan and Takhar. over 30 villages were destroyed completely and another 70 were severely damaged.[6]
Feb 11 1999	5.8	34.31	69.24	Logar/Vardak province	This strong earthquake destroyed approximately 7,000 houses, killing 70, injuring about 500 people, and making at least 14,000 homeless.
March 25 2002	6	36.01	69.37	Nahrin district	"According to the estimates of the Afghanistan Interim Authority (AIA), the number of dead is approximately 1,800 with 1,200 bodies counted so far, nearly 4,000 people were injured, approximately 1,500 homes were destroyed and 20,000 people were left without shelter.[7]

After the year 2003, strong earthquakes in Afghanistan include the magnitude 7.5 earthquake of Jurm district (36.524°N, 70.368°E) in Hindu Kush mountain range on October 26, 2015 that killed more than 115 people and injured more than 538 in the country,[4] and the series of three earthquakes on 11 June 2012, that hit Afghanistan's Hindu Kush region in North Eastern Afghanistan. These earthquakes killed 75 people in four districts in Baghlan province, while 13 people were injured. In addition, 114 houses were destroyed, 580 houses and 10 schools were damaged.[5] As the above table indicates, earthquakes in Afghanistan claimed thousands of lives in very recent past and cost hundreds of millions of dollars to the nation. In addition to the strong earthquakes inside the country, the major earthquakes in the neighboring countries i.e. Pakistan "2005 Kashmir earthquake having magnitude 7.6 earthquake, killing more than 86,000 people, 1935 Ali Jaan, Balochistan earthquake having magnitude 7.7, killing more than 30,000 people", and probably Iran "2003 Bam earthquake having magnitude 6.6, killing more than 30,000 people, 1990 Gilan and Zanjan earthquake having magnitude 7.4, killing about 50,000 people, and 1978 Tabas earthquake having magnitude 7.4, killing more than 15,000 people" all serves as a cautionary signals about what could happen in Afghanistan in terms of possible damages and loss of lives during earthquakes. As was previously mentioned, the "Current Practice of Earthquake Engineering in Afghanistan" has been studied in this paper in three major areas. These areas include the reliability of seismic input data, proficiency of earthquake engineering practitioner and readily used methods of analysis in engineering design, and adoption and enforcement of construction codes and standards. Each of the above areas is elaborated in the coming paragraphs.

Reliability of seismic input data

Although Afghanistan is continuously hit by earthquakes of various magnitudes, these earthquakes have not been translated into a relatively reliable seismic input data in terms of seismic hazard maps and seismographic records that can be used in analysis and design of construction and rehabilitation of the infrastructure in the country. Earthquake hazard maps are readily used by engineers to design buildings, bridges, highways, and utilities that will withstand shaking from earthquakes. Till 2007 Afghanistan did not have any earthquake hazard map. By this year, the first probabilistic earthquake hazard map "Preliminary Earthquake Hazard Map of Afghanistan[1]" was published by USGS and USAID. This map is currently used as a single source of information in seismic design of buildings and other structures in Afghanistan. The reliability of a seismic hazard assessment whether it is performed probabilistically or deterministically is mainly depending on the quality of characterization and detailing of seismic source (the active faults), relatively accurate earthquake magnitudes and rates of recurrence and application of appropriate attenuation relationships. Paleoseismology and records form seismographic stations are used to identify and characterized active faults. In addition, Historical accounts regarding earthquakes and data from seismographic stations are used to detect the occurrence of past earthquakes, to estimate their magnitude, and to identify their location.[5–7]

Most suspect faults have not been studied and characterized in sufficient detail to allow them to be explicitly modeled in a seismic hazard assessment.[1] As pointed out earlier, more than ten active faults are believed to be contributing to the seismic activities in Afghanistan while less than half of these faults have been incorporated into the seismic hazard assessment model that produced the "Preliminary Earthquake Hazard Map of Afghanistan". Even though the Chaman fault has the most evidence for seismic activity by far, the literature assigns widely variable characteristics to this single relatively well known fault. For instance, Wellman (1695) assigned a slip rate of 2-20mm/year, Tapponnier and other (1981) assigned a slip rate of 10-20mm/year over the last 100,000 years, a report cited by Lawrence and others (1992) indicate a slip rate of 25-35mm/year. A slip rate of 10mm/year has been assigned to this fault in preparing the "Preliminary Earthquake Hazard Map of Afghanistan". Compared to the time intervals at which large earthquakes occur, seismographs and seismographic networks have been available only in recent times (since around 1898). Thus, the information obtained from instrumental records is necessarily a small part of the information needed to establish the seismic hazard at a site, and has to be complemented with the information obtained from investigations based on historical accounts of earthquake activity in the distant past.[8] The current seismic hazard map of Afghanistan has not used pre-instrumental earthquakes data as they are highly uncertain in their magnitudes and locations. Beside this, the catalog of the instrumentally recorded earthquakes contains earthquakes of moment magnitude 4.5 and greater from 1964 to 2004. This short period of time will not contain enough of the seismic records compared to other parts of the world where earthquakes were instrumentally recorded from earlier time in 20th century to represent the locations, rates, and magnitudes of future earthquakes.

The use of appropriate ground motion prediction equations (GMPEs), or the attenuation relationships is also vital in preparing a reliable earthquake hazard map. Almost all of the recently developed attenuation relationships use earthquake magnitude, source to site distance, fault type and orientation, and local soil conditions as their input parameters. Because of unavailability of ground motion prediction relations specific to Afghanistan, the current "Preliminary Earthquake Hazard Map of Afghanistan" is developed using ground motion relations of regions of United States and Europe that are tectonically analogous to Afghanistan for shallow earthquakes. For intermediate-depth earthquakes (50–250 km), relations that were derived from global data sets that contained primarily earthquakes in subduction-zone tectonic settings are used since not enough data is available to guide ground-motion predictions for such earthquakes. A study on the reliability of GMPEs[9] concluded that the selection of effective database and the functional form of the GMPEs (especially at short distances) are the main sources of differences in predicting ground motion parameters. This reference also states that the available GMPEs, although greatly improved, are not yet fully reliable, especially at short site to fault distances. In addition to this, the Reliability of ground motion prediction relationships used in seismic hazard assessment of Afghanistan is greatly affected by the facts that faulting and seismotectonics of the country is not sufficiently understood and that no database of locally recorded ground motions is available that can capture and incorporate the effects of source to site distance and fault type in the resulting attenuation relations. In other words, faulting and seismotectonics of the country is not well studied and no local seismic records available that can be used in adopting appropriate attenuation relationships.

Earthquake engineering professionals and methods of analysis of structures

Having earthquakes tolerant infrastructure is highly depending on the overall knowledge of earthquake engineering practitioners, technology, and the readily used methods of analysis and design of structures. Earthquake engineering professionals are directly

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involved in development of infrastructure in a country and their proficiency of earthquake engineering is reflected in civil engineering structures designed and constructed by them. In developed countries with better earthquake resistant infrastructure, universities offer specialized graduate degrees in earthquake engineering and huge amount of investments are made each year on research at colleges and universities, industrial research laboratories, government institutions, and independent research institutes to develop and access technology, means and methods that results in more earthquake resistant infrastructure. Building, bridges, and other structures are analyzed using advanced and more accurate methods of analysis including Linear and Nonlinear Response History, Response Spectrum, and Pushover to determine strength and deformation demands in structures during earthquakes. Recently performance based design is developed to provide engineers with the capability to design buildings that have a predictable and reliable performance in earthquake. Performance based seismic design represents a necessary strategy for reducing earthquake losses.[10] Earthquake engineering professionals developed seismic protective systems and devices including base isolation systems, supplemental dampers, tuned mass dampers, and active control systems that are added to a structure to help the structure better resist earthquake effects. The current practice of earthquake engineering in Afghanistan in terms of earthquake engineering proficiency is discussed in the coming paragraphs.

The overall percentage of literate Afghan population and the highest degree of educations offered currently in Afghan public and private universities shall be a good indicative of the level of technical and professional knowledge about earthquake engineering in the nation. The higher rate of illiteracy in the country is perceived in any technical field including civil and particularly earthquake engineering. Currently, Afghan universities include earthquake engineering as a single course in their curriculums taught to undergraduate students. No specialized graduate degrees are offered in this field. Most of the structural engineers involved in seismic design are those without graduate studies and with limited knowledge about earthquake engineering they gained during their undergraduate studies. There also have been structural and earthquake engineers with graduate degrees they obtained abroad in the field of earthquake engineering. However, their number can be judged very limited in comparison to the demand in the country. The limited understandings of practicing engineers about advanced earthquake engineering concepts leave them incapable of performing advanced and more accurate structural analyses. Beside this, engineers with professional graduate studies and with relatively broader insight into earthquake engineering are also unable to apply sophisticated and more advanced methods of structural analyses such as nonlinear response history that can produce reliable results. For this, there are two main reasons: firstly, there is no locally recorded database of ground motions available that can be used to select and scale earthquake ground motion records for such analyses. Secondly, the faulting and seismotectonics of the country are not well understood that will enable engineers to use available databases such as PEER NGA to an appropriate degree of reliability, since selection and scaling of earthquake ground motion records for such analyses depends on magnitudes, fault distance, and source mechanisms that are consistent with those that control the maximum considered earthquake.[11] Consequently, the lack of professional knowledge and necessary data together leave earthquake engineers in Afghanistan with the choice of using simplified static methods of analysis such as equivalent lateral force method, although the application of this method is subject to the limitations imposed in its development including seismic activity of the site, maximum height, and structural irregularities of buildings.[12]

Enforcement of construction standards and codes

The adoption and enforcement of latest construction standards and seismic design codes is considered as an important factor in saving lives and reducing losses from earthquakes. The saying that "Earthquakes don't kill people, buildings do." signifies the importance of code compliant design and construction of structures for seismic risk reduction. Building codes and standards governs the design, construction, repair, and maintenance of structures and specify the minimum requirements to adequately safeguard the health, safety, and welfare of building occupants. Seismic design and construction codes and standards refer to the seismic design requirements included within building codes. Communities who adopt and enforce seismic codes suffer much less damage than those without such codes. The Loma Prieta earthquake occurred on October 17, 1989 and the Northridge, California, earthquake of 1994 shows the effectiveness of seismic codes in reducing the losses of lives and property from earthquakes.[13] In these earthquakes, most of the damage occurred to unreinforced masonry buildings built before the adoption of seismic codes while nearly all of the building built after the adoption of seismic code survived the shakings.

The Department of National Construction Standards and Codes was established in 1985 within Ministry of Urban Development and Housing of Afghanistan for the purpose of research for publication and adoption of buildings construction codes and standards. Although construction codes and standards have been adopted in parts, these adopted codes are not used widely in the country and the construction industry widely uses model building codes directly. The reasons for this shall be lack of enforcement of these adopted standards by relevant government building officials, inadequacy of/ ambiguity in adopted standards, and the fact that construction projects funded by foreign donors require the use of their own recommended model codes and standards. In addition, the lack of professional knowledge as mentioned in previous section, uncertainty and lack of availability of data needed for adoption of codes resulted in inappropriate adoption of design and construction codes and standards. Building codes are only effective if adequately enforced. Code enforcement is the responsibility of local government building officials who review design plans; inspect construction work, and issue building and occupancy permits. Local municipalities are main governmental bodies that provide such services for private construction sector in Afghanistan. Lack of rule of law in the community, lack of professional knowledge, lack of public awareness about essence of code enforcement, and corruption are the main obstacles that lead to insufficient application and enforcement of building design and construction codes within the Afghan community. The lack of sufficient enforcement of seismic design and construction codes resulted in highly vulnerable infrastructure especially in highly populated urban areas. It shall be noted that due to the inevitable nature of the earthquakes occurrence in earthquake prone countries such as Afghanistan, it is crucial that proper preparedness and emergency measures and planning should be undertaken prior to and in the event of an earthquake disaster. The topic of earthquake disaster management is beyond the scope of the current paper and therefore is not elaborated.

Conclusion

The aim of this article was to explore how much reliable is the current practice of earthquake engineering in Afghanistan? As various

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parts of this country is continuously hit by earthquakes of various magnitudes. Earthquake engineering practice was explored in three major areas.

These areas were

I. Reliability of seismic input data,

II. Earthquake engineering proficiency and methods of analysis of structures, and

III. Adoption and enforcement of building design and construction codes and standards. The study concluded that the only available and currently widely used preliminary seismic hazard map (seismic input data) of Afghanistan may not be considered as a reliable source of information for seismic design because of the insufficient detailing of seismic sources, unavailability of local seismographic and historical records and the usage of unsuitable attenuation relationships.

The study also concluded that the higher rate of illiteracy in the country is perceived in any technical field including civil and particularly in earthquake engineering field. Additionally, no specialized graduate educational programs are offered in this field in Afghan private and public universities. This leaves Afghan engineers incapable of performing advanced seismic analyses of structures and ultimately resorting to simplified and inaccurate analyses of important structures. Design and construction codes are not properly adopted because of the lack of professional knowledge and needed information for codes adoption. Lack of rule of law, professional knowledge, public awareness, and corruption were mentioned as the main obstacles against enforcement of design and construction codes. Overall, this paper concludes that the current practice of earthquake engineering in Afghanistan is not adequately reliable and therefore building and other infrastructures are either under-designed or over-designed. As the design goes to construction phase, both designs result in sub-standard infrastructure. Under-designed structures threaten lives and cause economic losses during strong earthquakes, while over-designed structures are not economical and have wasted resources.

Recommendations

Considering the findings of this paper, the following recommendations shall be made for enhancing the reliability of current practice of earthquake engineering in Afghanistan.

i. For reliable seismic hazard quantification, active seismic faults need to be identified and detailed for their types, slip rates and other relevant features.

ii. Seismographic stations needs to be installed inside the country at appropriate locations. Local seismographic records are needed for selection and scaling of ground motion records for advanced dynamic analyses of structures. Beside this, local seismographic records are important in adoption or derivation of appropriate attenuation relationships and also provide relatively accurate estimation of earthquakes magnitude-recurrence relationships.

iii. Highly technical personal needs to be employed at key policy making bodies of the government that influence earthquake engineering practice.

iv. Educational and research institutions are vital in producing earthquake tolerant infrastructure in a country. Universities need to offer graduate programs and advanced topics in seismic design.

v. Seismic design and construction codes have to be adopted considering the actual conditions and accurate information from the country.

vi. Code compliant seismic design and construction of structures for seismic risk reduction is of vital importance. Therefore, it must be assured that buildings and other structures are designed and detailed according to the adopted codes and standards.

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Conflict of interest

The authors declare that they have no conflict of interest.

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