Engineering Contribution to the Field of Emergency Management

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Abstract

Engineering has contributed to the emergency management field in two important ways: in the setting of design and safety standards, and the actual design and construction of infrastructure used to prevent damage and losses caused by hazards. In this chapter the contribution of engineering to emergency management is presented. First, the evolution of the setting of engineering codes and standards in the United States is presented. Then, the contribution of engineering to hazard reduction is given by type of hazard and by type of infrastructure. Finally, conclusions and recommendations for future engineering research are presented.

Introduction

This chapter presents the main contribution of engineering to the emergency management field. Engineering encompasses several fields of study that have core engineering sciences in common (Channell 1989). Rather than describe the contributions of each of the various engineering fields (e.g., civil and structural engineering, chemical engineering), the chapter will look at how engineering in general has contributed to hazard reduction.

Engineering has contributed to the emergency management field in several ways; helping communities reduce the risk from natural and technological hazards, but also in some cases contributing to the overall risk. This is illustrated in the following example. Important engineering flood control projects were implemented during the 1930s-1960s after the passing of the Flood Control Act in 1934. These flood control projects involved large and expensive construction ventures such as building of levees and floodwalls. An evaluation of a series of disasters in the late 1960s (particularly hurricanes Betsy and Camille) in the United States proved that engineered flood control measures alone, particularly structural mitigation measures, could often disrupt or destroy the natural environment, could be extremely costly, and could create a sense of false security (Godschalk 1999). A need for non-structural mitigation alternatives for flood control (e.g., land use planning, relocation, protection of natural environmental features) was called for. Thus, protection of people and property from the impacts of natural and technological hazards requires a balanced use of engineered-measures as well as non-engineered ones.

Two of the most important contributions of engineering to emergency management have been in the setting of codes and standards, and the actual design and construction of infrastructure used to prevent damage and losses caused by hazards. The following sections describe the evolution of engineering codes and standards in the United States, and present the contribution of engineering to emergency management by type of hazard and by type of infrastructure.

The Evolution of Engineering Codes and Standards

Engineering design codes and safety standards in the United States have evolved over the years to incorporate lessons learned from past disasters or failures, as well as from research performed in the laboratory. The task of setting engineering design and safety standards has often been the responsibility of engineering associations such as the American Society of Civil Engineers (ASCE), the American Society of Mechanical Engineers (ASME), or the American Petroleum Institute (API). The main purpose of setting design and safety standards has been for public safety and hazard reduction. However, the appropriate level of safety is not solely the decision of engineers or manufacturers but a societal choice. Thus, who participates in the decision making process and how these choices are made are crucial (Heaney *at al.* 2000). There is of course much debate on whether the public's interests are always fully considered (Keeney 1983, Heaney *et al.* 2000). However, this discussion is outside of the scope of this chapter.

Until recently, design and safety standards have been set with primary regard to life safety issues. For example, buildings codes can assure that buildings are designed so that occupants can evacuate safely from a building, but they do not guarantee that the building itself will be inhabitable after a design level event. Recently, changes to codes and standards have been incorporated to minimize property damage, or to assure structural integrity of buildings. Heaney *et al*. (2000) observe that building regulations may now include other considerations such as accessibility for the disabled, historic preservation, and decrease of economic loss during design-level events.

Engineering codes and standards alone do not guarantee safety from natural and technological hazards. While engineering codes and standards have tried to address acceptable levels of risk and losses, they have been difficult to enforce and administer. The extensive damage to residential buildings (more than 215,000) during the Kocaeli earthquake in Turkey in 1999 resulted among other problems as a consequence of lack of oversight of building regulations (U.S. Geological Survey 2000, Cruz 2003). Many buildings were constructed without any engineering input, or often even if design plans had been approved by city engineering officials, poor quality materials and unqualified workers were used. Heaney *et al*. (2000) note similar problems during Hurricane Andrew in Florida in 1992. The authors report that lack of building code enforcement was in part blamed for the widespread building damage caused by the high winds during the hurricane.

Engineering codes and standards are dynamic, changing over time as new research findings and lessons from past disasters are incorporated, and as society's acceptable levels of risk change. Bringing buildings and other structures up to current buildings codes periodically is expensive and not always economically feasible. In addition, there is often an administrative lag time before new codes are actually incorporated. Thus, hazard reduction in buildings and structures cannot depend solely on engineering codes and standards, but must incorporate other hazard reduction strategies such as land use planning, insurance, education and awareness campaigns, and other non-structural hazard mitigation alternatives. Knowing how to combine various hazard reduction strategies and how to work with the various actors and stakeholders represents a challenge for the emergency manager.

Engineering Contribution to Hazard Reduction by Type of Hazard

In this section the engineering contribution to hazard reduction is presented by type of hazard. This division is adopted from Heaney *et al.* (2000) because engineering practice has been organized by type of hazard, and by impact on type of infrastructure which will be described in a subsequent section.

Earthquakes

Earthquakes can have devastating effects on poorly constructed buildings and other infrastructure resulting in huge losses of life and property. Such is the case of the Kocaeli earthquake in Turkey in 1999 where more than 17,000 people lost their lives. Approximately 214,000 residential units and 30,000 business units sustained structural damage in the earthquake, and many complete or partial building collapses were reported (U. S. Geological Survey 2000). Economic losses for the Turkey earthquake were estimated at US$16 billion (Tang 2000). In the U. S. earthquakes have also taken their toll particularly in economic terms. Thousands of structures were damaged or destroyed by ground shaking during the Northridge earthquake in 1994, and total direct losses were estimated at more than US$20 billion (Tang 2000).

Although the State of California has taken steps towards earthquake hazard reduction since the 1906 San Francisco earthquake, a national earthquake mitigation policy was not adopted until 1977 through the National Earthquake Hazards Reduction Program (NEHRP). The goals of the NEHRP include improving the understanding of earthquakes and their effects (e.g., predicting and forecasting), improving techniques to reduce seismic vulnerability of facilities and systems (e.g., through the adoption of updated seismic building codes and better construction practices), and improving seismic hazards identification (e.g., development of earthquake hazard maps) and risk-assessment methods and their use.

Earthquake engineering activities have mostly centered around impacts on buildings and lifeline systems (Heaney et al. 2000). The engineering design and construction of infrastructure (e.g., buildings, lifelines) to withstand earthquakes is vital, particularly in areas of high seismic risk. The adoption of appropriate seismic building codes for new structures and the retrofitting of older buildings to current engineering building codes can help minimize loss of life and property during earthquakes. In the United States adoption and enforcement of seismic building codes is left to the discretion of each state, with the exception of some seismic requirements for new and existing federal buildings (Executive Orders 12699 and 12941). The state of California, for example, has adopted the Unified Building Code (1997), which requires designing buildings for the 1 in 475-year earthquake event. However, some local communities in the state may choose to following stricter codes, such as the International Building Code

(2000), which requires the design of new buildings for the 1 in 2475-year event. Each state has adopted various seismic construction standards for new buildings. The problem remains for older structures.

Earthquakes have the potential to disrupt lifeline systems. For example, electrical power outages were caused during the Taiwan (Kranz 1999) and Turkey earthquakes in 1999 (Tang 2000), the Kobe earthquake in Japan in 1995 (Erdik 1998), and the Northridge earthquake in the United States in 1994 (Lau et al. 1995). Extensive damage to transportation routes was reported following the Kobe earthquake, which destroyed the city's main highway, several railroad tracks, and much of its port (Dawkins 1995). Lau *et al.* (1995) reported extensive damage to gas distribution systems during the Northridge earthquake in California. This resulted in numerous fires, which consumed several single-story wood frame houses and over 70 mobile homes in the cities of San Fernando and Sylmar.

Damage to lifelines can have detrimental effects on emergency response activities. Loss of water due to multiple pipeline-breaks delayed emergency response to several of the gas-caused fires following the Northridge earthquake (City Administrative Officer 1994). Steinberg and Cruz (2004) reported that loss of water and power outages following the Kocaeli earthquake hampered emergency response to earthquake-triggered hazmat releases.

Experience and observations during past urban earthquakes in the U.S. and around the world are used by engineers to assess vulnerability of lifelines to earthquakes (Erdik 1998). After the 1971 San Fernando earthquake in California, which caused extensive damage to all types of lifelines, efforts were made to better understand the effects of earthquakes on lifelines and to advance the practice of lifeline earthquake engineering in the United States (Eguchi and Honegger 2000). The Technical Council on Lifeline Earthquake Engineering, established after the San Fernando earthquake, develops guidelines and standards for the seismic design and construction of lifelines including electrical power and communications systems, gas and liquid fuel pipelines, transportation systems, and water and sewage systems (Heaney *et al*. 2000).

Lifeline vulnerability functions and estimates of time required to restore damaged facilities are provided in the ATC-25 report (ATC 1991) "Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous United States" (Rojahn et al. 1992). The vulnerability functions are based on inventory hazard data and the elicitation of expert opinion methodology developed in the ATC-13 report (Erdik 1998).

Floods

Floods account for about 80% of all declared disasters in the United States. Heaney *et al*. (2000) observe that flood control in the United States represents a typical example of the long-term evolution of engineering design standards. The strong emphasis on mostly structural engineering flood control measures in the 1930-1960s proved unsustainable. The Midwest floods in 1993 led to a re-evaluation and change in flood control policies in the nation, moving towards more integrated flood control management that combines structural and non-structural hazard reduction options (Godschalk *et al*. 1999).

Pilgrim (1991) notes the need for the engineering profession to broaden its scope from the merely technical aspects to those that directly affect communities and the environment. The author observes that the basic role of the engineer is shifting to provide more effective flood hazard reduction solutions. Thus, he adds, sociological, political, and environmental considerations are receiving increased recognition alongside technical aspects in order to provide effective flood mitigation alternatives for the community.

The United States Army Corps of Engineers (USACE) has done extensive work in flood mitigation control. The report “Flood proofing techniques, programs, and references”, prepared for the USACE, presents a comprehensive review of flood proofing techniques (USACE 1997).

Hurricanes

Hurricanes represent a major threat to areas in the United States along the east coast and the Gulf of Mexico. Although hurricanes are considered rare events (e.g., the probability that a particular 50-mile segment of coastal area along the U. S. Gulf Coast will be hit by a major hurricane in any given year is very low, ranging from close to 0.0% to 4.0%[1]), nonetheless when a major hurricane makes landfall the results can be devastating. Hurricane Andrew, which impacted Florida and Louisiana in 1992, was considered one of the most costly disasters in U. S. history with economic losses estimated at almost $30 billion dollars (Jarell 2001). In 2004, Florida and parts of the southeastern U. S. were impacted by four hurricanes in a period of six weeks. Hurricanes Charley, Frances, Ivan and Jeanne caused dozens of deaths, left thousands of people homeless, and knocked out power service for millions of people. These hurricanes were accompanied by high winds, torrential rainfall, storm surge and flooding, and hurricane-spawned tornadoes. According to the Federal Emergency Management Agency (FEMA 2005) the 2004 Atlantic Hurricane Season was one of the busiest and most destructive in U. S. history.

[1] Petak and Atkisson (1982)

Engineering hazard reduction measures can be taken to minimize the loss of life and property during hurricanes. One of the main threats of a hurricane is the high wind speed. Engineering design codes are used to insure that buildings and structures are constructed to withstand particular wind speeds depending on the climatic characteristics of each region. The design wind speeds have been updated over the years, and in general the new codes require the use of higher design wind speeds (Cruz *et al*. 2001).

In the United States, ASCE provides the guidelines for the design and calculation of wind loads in the design standard *ASCE 7* "Minimum Design Loads for Buildings and Other Structures" (ASCE 7 1998). Theses provisions have been incorporated into other buildings codes (e.g., Uniform Building Code) (Cruz *et al*. 2001).

Heaney *et al*. (2000) point out that too often hurricane damage to residential structures is due to failure of roofing materials, doors and windows, and that these failures lead to weather penetration and damage. They note that during Hurricane Andrew, most damage losses in buildings were due to penetration of the weather envelope and not by the failure of major structural components. ASCE 7 has incorporated provisions for protecting the building envelope.

Droughts

Recent droughts in the United States since 1995 have demonstrated the vulnerability of the country to droughts despite improvements in weather forecasting and the development of new tools and technologies (Hayes *et al*. 2004). The U. S. Army Corps of Engineers evaluated the impacts of droughts in the United States (Dziegielewski *et al.* 1991). FEMA's "National Mitigation Strategy" report published in 1995 estimated drought losses as high as $8 billion (FEMA 1995).

Droughts are slow-onset and relatively long-lasting events, sometimes making it difficult to determine when a drought begins. Droughts involve issues related to the supply and demand of water resources (Hayes *et al*. 2004). Therefore, drought hazard mitigation will involve both physical and social issues. Due to their complexity, there is no single universal remedy against these water-related extremes (Budhakooncharoen 2003). Budhakooncharoen (2003) observes the need for a holistic approach involving applications of sustainable integrated water resources and comprehensive risk management. Therefore, both engineering and non-engineering approaches are needed for appropriate drought mitigation and risk management. Hayes *et al*. (2004) based on Wilhite (1997) and Wilhite and Vanyarkho (2000) present nine categories of state government actions in the U. S. for drought mitigation. Some of these include assessment programs, water supply augmentation and development of new supplies, technical assistance on water conservation and other water-related activities, and demand reduction/water conservation programs.

Landslides

Landslides and other ground-failure problems affect all 50 States and U.S. Territories. 36 States have moderate to highly severe landslide hazards (Spiker and Gori 2003). Landslides are responsible for substantial human and economic losses in the United States. It is estimated that every year landslides cause 25 to 50 deaths, and cost between $1 and $3 billion in economic losses (National Research Council 2004).

Landslides often accompany other natural hazards such as earthquakes, floods, hurricanes, and volcanic eruptions. The Northridge earthquake in 1994 triggered more than 11,000 landslides to the North and North West of the epicenter in the Santa Susana Mountains and the mountains north of the Santa Clara River valley (Jibson 2002).

Hurricane Mitch in Central America in 1998 resulted in deadly landslides, which caused the majority of fatalities (Spiker and Gori 2003).

The U. S. Geological Survey (USGS) has taken the lead in developing a national landslide hazard mitigation strategy. Spiker and Gori (2003) outlined the key elements of this strategy which include: (1) research; (2) hazard mapping; (3) real-time monitoring of active landslides; (4) loss assessment to determine potential impacts; (5) information collection, interpretation and dissemination; (6) guidelines and training of scientists, engineers, and decision makers; (7) public awareness and education; (8) implementation of loss reduction measures; and (9) emergency management.

As with other natural hazards, landslide hazard reduction includes both engineering and non-engineering measures. Engineering mitigation measures used include construction of earth-retaining structures, construction of surface water drainage systems, slope surface protection such as hydro-seeding, sprayed concrete and reinforced concrete grids, and re-compaction of fill slopes (Kwong *et al.* 2004). Tunnels, although expensive, usually prove to be cost effective in the long term to avoid landslide hazard in transportation routes with slope problems (Bhasin *et al.* 2001). Spiker and Gori (2003) observe the need to establish standardized codes for excavation, construction and grading in landslide prone areas, as there is no nationwide standardization.

Fires Associated with Disasters

Natural and technological disasters can cause secondary events such as fires. Fires following earthquakes have caused the largest single losses due to earthquakes in the United States and Japan (Scawthorn *et al.* 1986, Della Corte *et al.* 2003). The California Seismic Safety Commission (CSSC) (ASCE-25 2002) reported approximately 110 earthquake-related fire ignitions due to gas pipeline breaks during the Northridge earthquake, and Menoni (2001) reported the destruction of almost 7000 buildings due to fire following the Kobe earthquake in Japan in 1995. The Turkey earthquake in August 1999 triggered multiple fires at one of Turkey's largest oil refineries (Steinberg and Cruz 2004), and the recent Tokachi-oki earthquake in Japan in 2003 triggered a major fire in the oil storage farm of an oil refinery (Kurita, 2004).

Heaney *at al.* (2000) report that approximately 18 deaths and $180 million in economic damages are attributable annually to fires caused by natural disasters. A percentage of these losses result from damage to the natural and built environment caused by wildfires. Engineering approaches for fire hazard mitigation may include measures to prevent or delay fire ignition and fire spread, and to improve fire suppression (Zaghwl and Dong 1994). Approaches for mitigation of losses caused by wildfires are presented in the Standard for Protection of Life and Property from Wildfire (National Fire Protection Association 2002) and the *Urban-Wildfire Interface Code* (International Code Council 2003).

Engineering Contribution to Hazard Reduction by Type of Infrastructure

Natural and technological hazards often impact buildings and other structures. Typical engineering taxonomy divides infrastructure into buildings and lifeline systems (e.g., bridges, pipelines) (Heaney *et al*. 2000). In this section, the hazards and contribution of engineering to hazard reduction in these systems is presented. It is important to note that much of the research concerning natural hazard impacts on infrastructure has been in the area of earthquake hazard reduction particularly in California. Nevertheless, the lessons learned from earthquake hazard reduction can often be implemented for other types of natural hazards.

Buildings

Buildings are affected by floods, high winds, soil problems, snow, fires and earthquakes. In addition, Heaney *et al*. (2000) remark that because buildings are complex combinations of the foundation and structure, and the plumbing, electrical, heating, ventilation, air conditioning, and ancillary systems they may suffer damage when one or a combination of these systems fail. The following of appropriate buildings codes (e.g., Unified Building Code) can reduce the potential damage caused by natural hazards. However, there are instances when non-engineering hazard reduction alternatives can be more effective or less costly. The emergency manager must pay special attention to areas that are at greater risk (e.g., residences built in flood plains, constructions on or near known earthquake faults), and to older buildings, which have not been retrofitted to newer codes.

Bridges and Roadways

Bridges and roadways can be affected by floods, high winds, soil problems and earthquakes. Liquefaction, ground settlement, and slope instability can cause extensive damage to bridges and elevated highways during earthquakes, and other landmass movements.

Engineers work to improve the structural integrity and performance of bridges and roadways. There has been extensive research of potential damage to these lifeline systems during earthquakes. The Applied Technology Council (ATC) report “ATC-25” (ATC 1991) assigns 1, 2, 8, and 20% damage, for earthquake MMI[2] levels of VII, VIII, IX, and X, respectively, for non-upgraded major bridges in California. Damage to conventional bridges for the same MMI levels respectively, are 3, 10, 25, and 80 %

[2] MMI – Modified Mercalli Intensity scale was developed in 1931 by the American seismologists Harry Wood and Frank Neumann. The scale is composed of 12 increasing levels of intensity that range from imperceptible shaking (I) to catastrophic destruction (XII).

(Erdik 1998). Erdik notes that the Northridge earthquake caused heavy damage to 10 viaducts and 157 overpasses. In addition, collapse and other damage (to bridges) resulted in the closing of 11 major roads in downtown Los Angeles.

Damage to transportation systems has often resulted in traffic congestion, and longer travel times delaying the arrival of emergency response teams and supplies. Damage to transportation systems has sometimes resulted in the complete isolation of whole communities. Identifying reliable transportation network designs that take into account accessibility/congestion, and dispersion/concentration of road networks is an area that is receiving increased attention (see Asakura and Kashiwadani 2001; McFarland and Chang 2001; Sakakibara, Kajitani, and Okada 2001).

Underground Pipelines

Underground pipelines can be affected by earthquakes, poor ground conditions, liquefaction, flooding, storm surge, erosion and landslides. Experience from earthquakes around the world indicates that underground pipeline damage occurs in areas of fault rupture, liquefaction, and poor unstable ground (Erdik 1998). Earthquakes have caused extensive damage to gas, water and wastewater and oil pipelines. Damage to gas pipelines can result in leaks, fires and explosions (Lau et al. 1995).

Engineers use field data from past disasters to estimate potential future damage to pipeline systems. Based on world wide data, Erdik reports that about 0.5-1 gas pipe breaks per one kilometer pipe occur during shaking intensity level VIII, depending on soil and pipe conditions. Rates can increase about 50 % in shaking intensity level IX. The California Seismic Safety Commission (CSSC) (ASCE-25 2002) reported 35 gas system failures in older transmission lines, 123 failures of steel distribution mains, 117 failures in service lines, and 394 corrosion related leaks following the Northridge earthquake, an earthquake that has been considered mild with respect to future earthquakes that can be expected in the region.

It is estimated that in California water distribution lines can suffer 0.5, 1, 4, and 12 pipe breaks per kilometer, respectively, for MMI shaking values of VII, VIII, IX, and X according to ATC-25 (Erdik 1998). Erdik observes that about half of these damage rates are applicable to gas lines, while about double these rates are applicable to sanitary sewer lines. Damage to water distribution lines was a major problem for fire protection following the Northridge earthquake (City Administrative Officer 1994). Erdik (1998) reports over 2,000 water line breaks during the Kobe earthquake, having a negative effect on fire- fighting capabilities. Steinberg and Cruz (2004) reported that damage to the main water pipeline, which provided service to several industrial facilities in Korfez, severely hampered emergency response to the multiple earthquake-triggered fires at Turkey’s largest oil refinery following the Kocaeli earthquake.

Ports and Marine Terminals

Ports and marine terminals are susceptible to hurricane winds and storm surge (Hanstrum and Holland 1992). For example, several ports in Central America were severely affected by Hurricane Georges in 1998 (Beam *et al.* 1999). Protection of ports and harbors from wave action and storm surge may include natural or man-made breakwaters and surge barriers.

Ports and marine terminals are also affected by earthquakes and tsunamis, and liquefaction and soil stability problems during earthquakes (Tang 2000, Erdik 1998). Tang (2000) reported that ground shaking, settlement, and lateral displacement caused damage to port facilities on both the south and north shores of Izmit Bay following the Kocaeli earthquake. Erdik (1998) reported that widespread liquefaction and permanent ground deformation devastated the Port of Kobe, Japan, damaging more than 90 % of the port's berths.

Damage to ports can have a severe economic effect on a region, as occurred following the Kobe earthquake, cutting Kobe off from the rest of Japan a.nd the outside world (Cataldo 1995). In addition, damage to port terminals of industrial facilities may result in spills at loading docks, such as occurred at Turkey's largest oil refinery. Several naphtha and LPG spills into Izmit Bay from broken loading arms at the oil refinery were reported following the Kocaeli earthquake (Steinberg and Cruz 2004). The American Society of Civil Engineers' Ports and Harbors Committee has developed planning and design guidelines for small harbors (Sorensen et al. 1992), and the U.S. Army Corps of Engineers has done research concerning design and redevelopment of ports and harbors (Lillycrop *et al.* 1991).

Electrical Power Systems

Electrical power systems are highly susceptible to natural hazards. Damage to power systems can severely hamper emergency response capabilities. Power outages have been reported during most major hurricanes. Similarly, most major earthquakes have resulted in electrical power outages of varying lengths. Damage to electrical power systems during hurricanes is often caused by weather penetration of power stations and by toppling of transformers and electrical power lines and posts.

The most vulnerable components during earthquakes include generators and transformers, with damage often occurring due to improperly anchored equipment (Erdik 1998). Indirect damage to electrical power lines and poles caused by building collapse can also be extensive, as was documented by Tang (2000) following the Kocaeli earthquake. Potential damage values during earthquakes have been estimated. ATC-25

(ATC 1991) assigns 16, 26, 42 and 70% damage values for non-upgraded electric transmission substations, respectively, for MMI levels of VII, VIII, IX, and X. For distribution substations the respective damage values are 8, 13, 25, and 52 % (Erdik 1998).

Engineers work to find ways to avoid or minimize disruption of electrical power systems during natural disasters. However, as the damage values above indicate, damage to these systems during a natural disaster event may be unavoidable. Thus, research efforts also involve developing methodologies and strategies to quickly repair and restore electrical power service.

Engineering Research Needs

Heaney *et al.* (2000) present a comprehensive review of engineering research needs concerning codes and standards, and engineering research needs by type of hazard and type of infrastructure. The authors note that their results are highly influenced by the areas with current funding, which provide the resources to compile this information. The area with the highest research-funding budget is earthquakes ($ 13 million/year), followed by floods and hurricanes (each with less than $1 million/year).

Improvement, particularly when incorporating concerns beyond life safety issues, is needed in the area of codes and standards (Heaney *et al.* 2000). As society's perception of acceptable risk shifts, and as individuals and communities suffer ever-greater losses from disasters, the willingness to pay the price for stricter engineering codes and standards is also likely to increase.

Determining acceptable risk is an important issue in the setting of codes and standards. Derby and Keeney (1981) note that determining acceptable risk involves choosing the best combination of advantages and disadvantages from among several alternatives. What constitutes advantages and disadvantages will vary depending on the individuals or organizations involved in the decision making process. Thus, to insure that codes and standards are in line with public values, those in charge of setting engineering codes and standards must work towards a more equitable participation of all sectors (actors and stakeholders) of the population. In this context, the need for better integration of scientific input from the various disciplines with the views of all stakeholders and actors involved is also essential (Heaney *et al.* 2000).

It was noted that there is still a large gap between the setting of codes and standards and their actual adoption and implementation. This represents a major challenge for local government officials and emergency managers, as well as for the scientific and engineering community. Development and evaluation of more cost-effective mitigation options, such as cheaper construction materials and innovative construction practices that still provide the desired levels of safety may encourage more businesses and home owners to adopt codes or retrofit older buildings. In developing countries, where economic resources are scarce, there have been several efforts to develop low cost, locally based repair and retrofitting techniques for non-engineered, rural structures (see for example Asociacion Salvadoreña de Ingenieros y Arquitectos, http://www.asia.org.sv/).

The need for multihazard approaches to disaster management is increasingly called for. Heaney *et al.* (2000) note the need for more formal multihazard evaluation methodologies to assess the relative importance of the various hazards (e.g., earthquake, wind). To aid in this effort, the National Institute of Building Sciences (NIBS) established the Multihazard Mitigation Council (MMC) which works to reduce losses associated with natural and other hazards by promoting improved multihazard risk mitigation strategies, guidelines, and practices.

Further research is needed concerning the costs of disasters and the benefits of hazard mitigation (Heaney *et al.* 2000). There is relatively abundant data on deaths and injuries, and on losses caused by damage to buildings and infrastructure. However, there is limited data on the benefits obtained (cost not incurred) when a mitigation measure is effective. One effort currently underway at the MMC involves evaluating the data requirements and identifying possible methodologies to assess the benefits of hazard mitigation. Software programs such as FEMA's HAZUS-MH (http://www.fema.gov/hazus/) loss estimation methodology can be used to estimate potential damage and economic losses from earthquakes, floods and high winds. In addition to estimating economic losses due to natural disasters, HAZUS-MH can be used for emergency preparedness planning purposes as it provides estimates of number of possible deaths and injuries, as well as estimates of number of displaced households and shelter needs. Field *et al.* (2005) used HAZUS –MH to estimate potential losses caused by earthquakes of varying magnitudes along the Puente Hills blind-thrust fault beneath downtown Los Angeles. Their study points out the significant risk posed by this fault and other seismic sources in the region.

There is a need for more research concerning sustainable prevention measures and management of natural hazards. Disasters are complex events, which result from a combination of factors including urbanization, population growth and environmental degradation. Budhakooncharoen (2004) observes the need for more integrated disaster management that reduces human vulnerability to disasters, avoids past mistakes and satisfies a wide range of needs through sustainable hazard mitigation practices.

A research area that has received increased attention is the prevention of infrastructure failures and other technological disasters resulting as secondary effects of a natural or other large-scale disaster event. In 1996, the President's Commission on Critical Infrastructure Protection (PCCIP) was established to advance the understanding of the role of critical infrastructure systems in large-scale disasters. Infrastructure systems such as electric power, water, and telecommunications are becoming more and more interdependent. Thus, infrastructure failures in one system have the potential to "cascade" onto other systems, thereby severely compounding disruptions to society (McDaniels 2005). The recent large-scale blackout in the Northeast of the United States in August 2003, and blackout that started in Switzerland and affected almost all of Italy in September 2003 are examples of how a single significant event can cause widespread disruption.

Natural disasters have the potential to cause other type of secondary disasters such as hazmat releases. Cruz *et al.* (2001) studied impacts of tropical cyclones on an oil refinery. The authors recommended identifying and evaluating methodologies to quantify the risks associated with natural hazard-triggered hazmat releases at these and other industrial plants. Steinberg and Cruz (2004) and Cruz and Steinberg (2005) have studied hazmat releases triggered by earthquakes. The authors provide a review of research needs concerning prevention of, preparedness for and response to these conjoint natural and technological (natech) disasters. Cruz *et al.* (2004) present the state of the art in risk management of conjoint natural and technological disasters in Europe. Future engineering research needs concerning natechs include assessment of the potential impacts of external hazards (e.g., earthquakes, floods) on both structural and non-structural components of industrial plants that use or handle hazardous chemicals, and the need to develop probabilistic hazard maps depicting areas where these conjoint events are most likely.

Conclusion

This chapter has reviewed the contribution of engineering to the field of emergency management. The contribution of engineering has been important in the setting of engineering codes and standards, and in the development of engineering resources, tools, and methodologies for use in mitigating the impacts of natural and technological hazards on the built environment. However, engineered-hazard mitigation options alone do not guarantee protection from natural and other hazards. Therefore, a holistic multihazard perspective that integrates social, economic, and environmental issues to hazard reduction is preferred. The engineering professionals, who contribute to hazard reduction, will be increasingly required to work across disciplines, and with many actors and stakeholders.

Engineering has contributed to our overall understanding of natural hazards and their impacts and the vulnerability of the built environment to these hazards. Improved understanding of natural hazards results in better forecasting of natural hazards, and more effective disaster prevention and mitigation practices and preparedness planning. One such example is HAZUS-MH, which not only provides estimates of potential damage and economic losses from natural disasters, but also provides useful data for emergency preparedness and response planning.

Engineering will continue to contribute to hazard reduction as cities become ever more complex and interdependent, and as new threats emerge (e.g., impacts of climate change, water scarcity, terrorism). Engineers will be required to apply new knowledge and skills to develop innovative and effective ways to prevent, prepare for, and respond to future disasters.

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