MULTIHAZARD ISSUES IN THE CENTRAL UNITED STATES

UNDERSTANDING THE HAZARDS AND REDUCING THE LOSSES

Edited by James E. Beavers, Ph.D., P.E.

ASCE Council on Disaster Risk Management
Monograph No. 3
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Cover Photo: Flooding of the Russell and Allison Levee in Indiana, June 2008. Ronald Elliott/U.S. Army Corp of Engineers

Editor's Note

Undertaking major steps towards mitigating the effects of natural and technological hazards in the central United States is far past its time. This status report is an outcome of the American Society of Civil Engineers' (ASCE) Council on Disaster Risk Management (CDRM) symposium held as part of the ASCE annual meeting in Chicago, IL, on October 18, 2006.

ASCE's CDRM organized the symposium to take a snapshot of hazards and mitigating events in the central United States and/or look at what's going on in other states that could be helpful. There were 13 presentations that varied from changing the way engineers approach designing, or not designing, for every day hazards to specific recommendations for certain hazards. Nine papers have been written as a result of that symposium and are included in this monograph. The first monograph paper provides an introduction to natural and technological hazards in the central United States, while the remaining eight papers represent some of the topics presented and discussed at the symposium.

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Table of Contents

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Observations on Steps Toward Mitigating the Effects of Natural and Technological Hazards in the Central United States—An Introduction

James E. Beavers[1] and William J Hall[2]

Introduction

Regional definitions of the central United States vary from source to source. Wikipedia (2007) defines the region as including Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas (see Figure 1.1). Alternate definitions may include some or all of Alabama, Colorado, Illinois, Indiana, Kentucky, Michigan, Mississippi, Montana, New Mexico, Ohio, Tennessee, Wisconsin, and Wyoming.

In focusing on natural and technological hazards, it seems wise to first focus on some of the elements at risk in three states—specifically Missouri, Illinois and Tennessee—as examples. In addition, this paper briefly identifies a number of governmental regulations, followed by some comments on the three states, including some details on major natural and technological hazards and implications to the three states. This material is intended to place in perspective examples of the current risks, related regulation, and implications for the three states as examples.

The Central States

The Census Bureau estimates (Census Bureau States 2006a) that on July 1, 2006 there were more than 54 million people in the 11 solid states, an increase of 4 million compared to 2000 census. If we included all central states, the estimated population for July 1, 2006 exceeds 126 million, up from more than 117 million in the 2000 census. Thus, today, more than 126 million people are at risk to natural and technological hazards in the central United States.

The most frequent hazards in the central United States are fires, floods, thunderstorms, tornadoes, and winter storms. For example, more than 1,000 tornadoes touch down each year in the central United States resulting in lost lives and millions of dollars in damage. From 1976 to 2000, the average number of deaths per year from tornadoes was 54 (Brooks and Doswell 2001). It should also be mentioned that these central states experienced the most costly natural hazard in U.S. history, possibly exceeding $100 billion, when Hurricane Katrina made landfall in Mississippi and Louisiana in 2005.

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Figure 1.1. The Central United States.

Table 1.1 presents the Federal Emergency Management Agency's (FEMA) defined natural and technological hazards (FEMA 2006) showing 15 hazards for which FEMA must be prepared to respond. All central states have experienced some level of all of these hazards, except for tsunamis, volcanoes, and nuclear incident. In the case of a nuclear incident, the state of Tennessee did experience a nuclear incident in 1958 when a criticality occurred at the nuclear facilities in Oak Ridge, TN (CA 1958).

Table 1.1. FEMA Defined Natural and Technological Hazards

Dam Failure	Earthquake	Heat
Fire/Wildfire	Flood	Hazardous Materials
Hurricane	Landslide	Nuclear Incident
Terrorism	Thunderstorm	Tornado
Tsunami	Volcano	Winter Storm

Source: FEMA Web site.

DMA 2000

Because the United States continues to experience damaging natural and technological hazards yearly in almost every state, during the 106th Congress the Disaster Mitigation Act of 2000 was passed and is known as Public Law 106-390 (DMA 2000). This act was to amend the Robert T. Stafford Disaster Relief and Emergency Assistance Act to authorize a program for predisaster mitigation, to streamline the administration of disaster relief, to control the federal cost of disaster assistance, and for other purposes. The act states:

"(a) FINDINGS.—Congress finds that—
  (1) natural disasters, including earthquakes, tsunamis, tornadoes, hurricanes, flooding, and wildfires, pose great danger to human life and to property throughout the United States;
  (2) greater emphasis needs to be placed on—
    (A) identifying and assessing the risks to states and local governments (including Indian tribes) from natural disasters;
    (B) implementing adequate measures to reduce losses from natural disasters; and
    (C) ensuring that the critical services and facilities of communities will continue to . . ."

"(b) PURPOSE.—The purpose of this title is to establish a national disaster hazard mitigation program—
  (1) to reduce the loss of life and property, human suffering, economic disruption, and disaster assistance costs resulting from natural disasters; and
  (2) to provide a source of predisaster hazard mitigation funding that will assist states and local governments (including Indian tribes) in implementing effective hazard mitigation measures that are designed to ensure the continued functionality of critical services and facilities after a natural disaster."

The mitigation planning final rule (FEMA 2002) lists the following hazards to be considered: coastal storm, terrorism, volcano, severe storm, nuclear, virus threat, winter storm, mudslide/landslide, extreme temperatures, chemical/biological, earthquake, technological, fire, industry hardship, tornado, wildfire, hurricane/tropical storm, drought, typhoon, flooding, dam/levee break, and tsunami.

Title 44 of the Code of Federal Regulations Parts 201 and 206 (CFR 2002) states the following: "Section 322 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act or the Act), 42 U.S.C. 5156, enacted under §104 the Disaster Mitigation Act of 2000, (DMA 2000) P.L. 106-390, provides new and revitalized approaches to mitigation planning. This section (1) continues the requirements for a standard state mitigation plan as a condition of disaster assistance . . ." with the intent over a period of time to provide an opportunity to reduce the nation's disaster losses through mitigation planning. As stated, the language in the act, taken as a whole, emphasizes the importance of strong state and local planning processes and comprehensive program management at the state level. It also requires states to have an approved hazard mitigation plan to receive Stafford Act assistance. Finally, the rule states that all state mitigation plans must be reviewed, revised, and re-approved by FEMA every three years. It also requires states and localities (cities and counties) to have plans in effect that meet the minimum requirements under this rule as a condition of receiving mitigation assistance after November 1, 2003.

Many states had problems meeting not only the deadline but also the mitigation planning requirements. As a result, FEMA allowed states to get extensions (FEMA 2004). Today all 23 central states have an approved multihazard mitigation plan (FEMA 2007), and in most cases they can be accessed by going to the respective state's emergency management agency Web site. Although all states have an approved plan, many counties or parishes in the states still do not have an approved mitigation plan. For example, Tennessee has 95 counties, and only 33 have approved plans.

Study States

Rather than exploring the hazards and losses and mitigating activities of each central state, this paper focuses on three states that are generally representative of all central states: Missouri, representing a core state, and Illinois and Tennessee, representing states outside the core. More information about Tennessee is presented in Chapter 7 on the Tennessee Multihazard Mitigation Consortium.

Illinois. Illinois has the second highest population of the central states with slightly more than 12.8 million, ranks second in population density (231 persons per square mile) to Ohio, and has an area of 55,584 square miles (Census Bureau 2000). The state population is concentrated in the northeast section of the state and in particular in Cook County (Chicago area), with slightly more than 5.29 million people, second in the nation to only Los Angeles County at 9.95 million. Cook County has a population density of 5,684 persons per square mile, 25 times the state average. Another county, which represents west Chicago, is Du Page County, with 0.93 million. Thus, the Chicago area has nearly one-half (48.6 percent) of the state's population. Cook County is one of 13 counties in the United States where an earthquake could result in a million fatalities (Nichols and Beavers 2002).

Missouri. The estimated population for the state of Missouri on July 1, 2006 was 5.8 million and, with an area of 68,885 square miles, is the 11th ranked central state in population density with 85 persons per square mile (Census Bureau 2000). Although Missouri is 11th ranked in population density, it is seventh ranked in total population.

There is a major concentration of state population in the east section of the state around the metropolitan area of St. Louis with four counties (St Charles, St Louis, Jefferson, and Franklin) in the area, each with a population of more than 100,000. St. Louis County has the highest population of the four counties, with more than 1 million. These four counties have a total population exceeding 1.7 million, representing nearly 30 percent of the state's population. With an area of 507 square miles, St. Louis County has a population density of 2,001 people per square mile, more than 23 times the state average.

Tennessee. The estimated population for the state of Tennessee on July 1, 2006 slightly exceeded 6.0 million and, with an area of 41,217 square miles, is the fourth ranked state in population density with 146 persons per square mile (Census Bureau 2000). Although Tennessee is fourth ranked in population density, it is sixth ranked in total population.

There are five major concentrations of the state population among Tennessee's 95 counties amounting to about 39 percent of the state's population. These are Memphis and Shelby County in the south-west portion of the state with a population of 911,438, Nashville and Davidson County in the middle of the state with a population of 578,698, Knoxville and Knox county in the eastern portion of the state with a population of 411,967, Chattanooga and Hamilton County in the south-east with a population of 312,905, and finally Clarksville and Montgomery County, northwest of Nashville bordering Kentucky, with a population of 147,114. So relative to Missouri and Illinois, Tennessee's population is spread out across the state.

Natural and Technological Hazards

Natural Hazards

Routine Natural Hazards. Missouri, Illinois, and Tennessee routinely experience the natural hazards of flooding, heat, thunderstorms, and winter storms depending on time of year. While winter storms occur in all three states during winter months, Tennessee is likely to have fewer winter storms than Missouri or Illinois because it is below the 37-degree latitude. Thunderstorms, flooding, and tornadoes occur in these states mostly in the spring and summer months. Heat occurs during hot dry periods in the summer months.

In the Illinois Natural Hazard Mitigation Plan (NHMP), the Illinois Emergency Management Agency (IEMA) has rated natural hazards by county based on (1) historical occurrence of the hazard and or probability in the county; (2) vulnerability of the county based on its population, i.e., how close people live near the hazard and percentage of people affected by the hazard if it occurs; (3) the potential severity of the impact based on the respective county's damaged infrastructure and injuries and deaths; and (4) overall population of the county. This resulted in five rating levels: (1) low (0-12 points), (2) guarded (13-24 points), (3) elevated (25-36 points), (4) high (37-48 points), and (5) severe (49-60 points).

For these routine hazards, Illinois rated thunderstorms and winter storms as high or severe in all of its 102 counties (IEMA 2004). The flood and heat hazard ranged from guarded to high in all counties. The authors believe that Tennessee and Missouri would get similar results using the same rating system.

In Missouri's mitigation plan (SEMA 2004) the heat hazard is defined as a "silent killer" and the state emergency management agency wants people to be aware of the warning signs of heat-related illness, such as light-headedness, mild nausea or confusion, sleepiness, or profuse sweating. Missouri provides a list of precautions to prevent heat-related illnesses, and Illinois provides heat index charts.

Earthquakes. All three states are vulnerable to a severely damaging earthquake because of each state's proximity to the New Madrid Seismic Zone (NMSZ). Three large earthquakes have occurred in this zone, each having a magnitude greater than 7.2 M (M= moment magnitude) to possibly as high as 7.7 M in 1811 and 1812. These three central states are not the only states vulnerable to the NMSZ; Arkansas, Indiana, Kentucky, and Mississippi are also vulnerable. Fortunately, the NMSZ has not continued to produce such earthquakes. While this is good because none of these states have experienced a seriously damaging earthquake, except for the 1895 6.5 M earthquake that affected Illinois and Missouri, it is bad because the public does not perceive the area as having an earthquake threat.

Because of the vulnerability of these seven states to the NMSZ, in 1983 FEMA began forming the Central United States Consortium (CUSEC) by establishing contracts between FEMA and the seven states. Contracts were awarded on April 11, 1984, and the foundation for CUSEC was complete. The organization's primary mission is to reduce deaths, injuries, property damage, and economic losses resulting from earthquakes in the central United States.

U.S. Geological Survey (USGS) seismic hazard maps of the region developed for the International Building Code indicates design ground motions are as high as for San Francisco. This has resulted in substantial public policy issues in western Kentucky (KGS 2007) and in Memphis (The Commercial Appeal–Memphis 2003 and 2004).

Fire and Wildfire. Fire and wildfires are also routine hazards, but some states treat them as a technological rather than a natural hazard. The Tennessee Emergency Management Agency (TEMA) considers wildfire as a technological hazard because the accelerant in most cases has been due to hazardous material releases and other technological events (Beavers 2007a).

Tennessee also breaks wildfire down into two classes: urban fire and wildfire (TEMA 2002). Urban fire is defined as any instance of uncontrolled burning that results in major structural damage to residential, commercial, industrial, institutional, or other properties in developed areas. Wildfire is defined as any incident of uncontrolled burning in grasslands, brush, or woodlands.

Most wildfires occur during the summer and fall months during dry periods; however, they can occur in the winter and spring months. For example, in the spring of 2007 Tennessee had serious wildfires that destroyed cabins and homes in East Tennessee due to a shortage of rainfall (KNS 2007a).

In contrast to Tennessee, Missouri includes wildfires in its mitigation plan under natural hazards (SEMA 2004). Illinois does not.

Hurricanes. All three states experience some aspect of hurricanes, Tennessee more so than Missouri or Illinois for the same reason Tennessee does not experience winter storms, i.e., being closer to the hazard source. Neither Missouri nor Illinois considered hurricanes in their natural hazard mitigation plans.

Landslides. With respect to the landslide hazard, only Tennessee addresses this hazard directly. Illinois does not address landslides as a hazard in its NHMP (IEMA 2004) because most of the state is relatively flat. Missouri addresses landslide indirectly as a secondary event following earthquakes. Similarly, such differences exist among other central states, for example, the flat land of Iowa compared to the mountainous area of Colorado.

In Tennessee landslides are the least significant hazard (with respect to its effects upon citizens), and most often occur in the mountainous regions of the eastern part of the state. A major rockslide in 1998 shut down Interstate 40 near the Tennessee-North Carolina border for almost two months, resulting in major economic damage to the area, which is highly dependent upon tourism.

Tornadoes. Tornadoes are also a routine hazard for the central states, but have been separated out because very few citizens in each of the three states are affected by each state's annual tornado events. While all three states experience tornadoes, Tennessee experiences fewer tornadoes than Missouri or Illinois. Since 1950 Missouri has had an average of about 29 tornadoes per year ranging from an F-0 (wind speeds 40-72 miles per hour (mph)) to an F5 (261-318 mph) on the Fujita Scale. Illinois has averaged 31 during the same time period, while Tennessee has averaged 12.

Illinois rated 13 of its counties as high for tornadoes, while the remaining counties were rated as elevated or guarded. Missouri and Tennessee would produce a similar result if the same hazard rating process were applied, although Tennessee would have fewer counties rated as high because of the lower frequency.

The National Oceanic and Atmospheric Administration (NOAA) (2007) shows that all three states have experienced an F-5 tornado, defined as incredible damage where strong frame houses are lifted off foundations and carried considerable distance to disintegration, automobile-sized missiles fly through the air in excess of 100 yards, trees are debarked, and other incredible phenomena occur. In fact, all core central states except Arkansas and all eastern central states have experienced an F-5 tornado. Texas has had the most with six events, while Alabama, Iowa, Kansas, and Oklahoma have had five events each. All of Alabama's events have occurred in the northwest quadrant of the state. Illinois and Tennessee have had two events while Missouri has had only one.

Technological Hazards

Routine Technological Hazards. For the central states, the technological hazards are hazardous materials, nuclear incident, dam failure, and terrorism. Because the storage and transport of hazardous materials makes up a part of daily life in the United States, the authors consider hazardous materials as routine. While a hazardous material spill does not necessarily occur every day, they occur often enough to be considered routine. In Tennessee, which considers fire and wildfire a technological hazard, it is also considered routine and was discussed under natural hazards.

Dam Failure. A dam is defined by the National Dam Safety Act as an artificial barrier that impounds or diverts water and (1) is more than 6 feet high and stores 50 acre feet or more or (2) is 25 feet or more high and stores more than 15 acre feet. There are more than 80,000 dams in the United States that fit this description (SEMA 2004). Dam construction varies widely throughout the United States. Most dams are of earthen construction while the largest dams are built of reinforced concrete and are used for hydroelectric power.

Missouri has 656 regulated dams and a total of 5,244 (MDNR 2007). Tennessee has more than 1,000 dams, many of them small agricultural dams (TEMA 2002). There are some large dams within Tennessee, however, including those operated by the Tennessee Valley Authority and the U. S. Army Corps of Engineers.

There are currently over 1,200 regulated dams in Illinois on rivers and streams. While many of these dams are useful for water supply, navigation, recreation, power generation, and flood control, many others no longer serve their original function and may present safety problems in some cases resulting in loss of life.

In Missouri the problem of unsafe dams was underscored by dam failures at Lawrencetown in 1968, Washington County in 1975, Fredricktown in 1977, and a near failure in Franklin County in 1979. More recently, a severe rainstorm and flash flooding in October 1998 compromised about a dozen small, unregulated dams in the Kansas City area. Overall, many of Missouri's smaller dams are becoming a greater hazard as they continue to age and deteriorate.

Nuclear Incident. Fifteen of the 24 central states have nuclear power plants for a total of 29 locations with 44 reactors operating (NEI 2007). In addition, there are also 13 nuclear-related facilities in the central states (AA 2006). That number increases to 17 if you include the shut down Oak Ridge Gaseous Diffusion Plant; the operating Y-12 Security Complex in Oak Ridge, TN; the nuclear fuels facility in Erwin, TN; and the uranium conversion facility in Metropolis, IL. Three of those listed are no longer in operation—the Oak Ridge Gaseous Diffusion Plant, Rocky Flats nuclear facility near Denver, CO, and the Portsmouth Gaseous Diffusion Plant in Ohio—but a nuclear incident could still occur as these facilities are dismantled and cleaned up. A pilot plant using the gas centrifuge process for enriching nuclear fuel is being built at the location of the old

Portsmouth Gaseous Diffusion Plant in Ohio with plans to build a full facility in the future.

Of the 44 reactors in the central states, Illinois has the most with 11 reactors generating 48 percent of its own electricity with a capacity of 11,388 megawatts. Tennessee follows Illinois with three reactors generating 28.6 percent of its electricity, while Missouri has only one reactor generating only 8.8 percent of its electricity. The Tennessee Valley Authority (KNS 2007b) recently announced the start up of the second reactor at its Watts Bar Nuclear Power Plant that will increase its generating capacity.

Of the 17 nuclear facilities in the central states, Tennessee has three and Missouri and Illinois have one each. The potential for a nuclear incident always exists. In fact, a criticality occurred at the Y-12 Security Complex, Oak Ridge, TN, in 1958 (CA 1958). Recently, a close call occurred at the Nuclear Fuels Services Inc. facility in Erwin, TN, when nine gallons of highly enriched uranium was spilled (KNS 2007c). Although nine gallons was enough for a criticality, the liquid did not pool up into a form to cause a criticality. The event was considered an "abnormal occurrence" by the Nuclear Regulatory Commission. An abnormal occurrence is considered "significant from the standpoint of public health and safety."

Terrorism. Terrorism is a technological hazard or threat that must be considered. Missouri's mitigation plan states: "The new millennium has begun, and the emergency management community now faces threats different in many ways than past threats. Gone are the days when emergency management was only for natural disasters and nuclear preparedness. We now face more technologically and politically based hazards that demand the attention of the emergency management community. These new hazards include a number of threats that have not been adequately dealt with in the past, including hazardous materials releases, civil disorders, and terrorism." Oklahoma and Tennessee are two central states that have experienced terrorism. In Oklahoma's case, the act was the bombing of the Murrah Federal Building in Oklahoma City on April 19, 1995 that resulted in many deaths to innocent citizens.

The terrorist threat in Tennessee was to bomb or crash a plane into one of the three nuclear facilities operating near Oak Ridge. On November 11, 1972, three hijackers armed with hand grenades and guns forced a Southern Airways jetliner with 27 passengers and three crewmembers to fly over and around Oak Ridge, TN. They demanded $10 million and said if their demand was not met that they would bomb a facility or crash the plane (KNS 1972). As a precaution, the predecessor of the Department of Energy, the Atomic Energy Commission, closed the K-25 Gaseous Diffusion Plant (now know as the East Tennessee Technology Park), the Y-12 facility (now know as the Y-12 Security Complex), and the Oak Ridge National Laboratory. When some of the hijacker's demands were met, they asked to be taken to Havana, Cuba. The passengers and crew were then allowed to return to the United States. As a result of 9/11 all central states must be prepared to respond to a terrorist act and take mitigation measures to reduce the opportunities for a terrorist act to occur.

Losses from Natural and Technological Hazards

General. Like in other central states, people in Illinois, Missouri, and Tennessee suffer millions of dollars in losses from natural and technological hazards each year, and in some years these can be tens of millions. The average losses in these three states range from $15 million (Missouri) to $20 million (Tennessee) per year. If we assume these losses are similar for all central states, the losses run from $360 to $480 million annually. Many of these losses can be prevented through proper education and mitigation.

Missouri. In Missouri, presidential disaster declarations since 1975 have primarily been related to severe storms and flooding (SEMA 2004). There have been 25 declarations since then, almost one per year. The flood hazard ranks first as a contributing factor in 18 declarations. Severe storm hazard ranked second contributing to 16 of the declarations. The tornado hazard ranked third contributing to nine declarations, while drought, ice jam, and ice storm ranked last, contributing to one declaration each. Missouri's largest single event loss was the 1993 Mississippi and Missouri River flooding. Federal expenditures exceeded $6 billion (Gray 2007). Including insured and self-insured, these losses exceeded $20 billion.

With respect to lives lost in Missouri, tornadoes have been the leading cause. On May 27, 1896, a tornado hitting St. Louis resulted in 306 deaths and more than $15 million in damage. The Great Tri-State tornado of March 18, 1925 touched down near Ellington, MO, stayed on the ground for 3.5 hours, and traveled into and across southern Illinois and into Indiana for a total of 219 miles before dissipating. This tornado resulted in 695 deaths, 2,000 injuries, and 15,000 destroyed homes (Westra 1998).

Illinois. Since 1957, Illinois has had 42 Federal disaster declarations (IEMA 2004) and like Missouri almost one per year. The flood hazard ranked the highest by being a contributing factor in 29 of declarations. The tornado hazard ranked second being a contributing factor in 16 of the declarations. Severe storms ranked third being a contributing factor in five declarations. Snow ranked fourth contributing to two declarations and an ice storm ranked last contributing to only one declaration.

According to the Illinois mitigation plan, the largest single loss from a natural or technological hazard event was the 1993 flooding of the Mississippi, Illinois, and Ohio Rivers, which exceeded $15 billion in damages and affected 39 of Illinois' 105 counties (IEMA 2004).

The Great Tri-State tornado took 541 lives between Gorman, IL, where it entered southern Illinois, and West Frankfort, IL, a distance of 40 miles. Interestingly, this tornado was not a severe tornado. It was later rated as an F-2 having wind speeds of 113 to 157 mph.

Tennessee. Since 1800, Tennessee has experienced more than 450 natural and technological disasters (Whaley 2007), ranging from the 1865 Sultana Riverboat explosion near Memphis, TN, which resulted in the deaths of 1,800 people, to the 2002 Mosey Grove tornado, which resulted in eight deaths. Tennessee's largest single loss was the ice storm of 1994. This resulted in $50 million (federal dollars) of road repair and public building costs (Whaley 2002), and based on similar losses, state, county, and private losses could have exceeded $450 million (Beavers 2007b). See Chapter 7 (Tennessee Multihazard Mitigation) for more information on Tennessee hazards and losses.

The April 7, 2006, Gallatin, TN, tornado, which killed seven people and was described as the most deadly single tornado in Middle Tennessee since the April 3, 1974 central U.S. super outbreak, was only an F-3 having wind speeds 158-206 mph.(NOAA 2006).

Education, Planning, and Mitigation

General. Education, planning, and mitigation are all required to reduce losses from natural and technological hazards in the United States. The U.S. Congress took the right step in establishing the DMA in 2000. However, it is just a first step. As another step in education, planning, and mitigation, the Council on Disaster Risk Reduction (CDRM) of the American Society of Civil Engineers (ASCE) held a symposium in Chicago, Illinois on October 18, 2006 in concert with ASCE's annual meeting. The symposium was titled "Multihazard Hazard Issues in the Central United States." The remaining papers in this monograph highlight some specifics issues of mutihazards related to education, planning, and mitigation.

Chicago Symposium. At the symposium held at the Westin Chicago River North Hotel on October 18, 2006, some 12 speakers presented invited papers. These papers, purposely broad in coverage, dealt with various aspects of natural multihazard issues, and to a lesser extent with technology (man) generated issues. The papers outlined some of the more important issues that should be addressed in developing comprehensive national and state hazard planning and action scenarios. Following is a brief overview of the principal points addressed in the full papers presented at the symposium and included in this monograph.

Keynote Paper: A Changing Perspective—Major Challenges

by William J. Hall

The author focuses briefly on four principal topics: (a) the multihazards (natural and man-made), (b) observations on risk assessment and risk coverage, (c) mitigation measures, and (d) education and training. He presents a brief discussion of issues that must be addressed to make significant improvements in our ability to plan, design, and construct/develop mitigation measures for the noted hazards in the years ahead.

The Context for Successful Loss Reduction from Natural and Technological Hazards as Applied to the Central and Eastern United States

by W. P. Graf

The author discusses such issues as (a) incremental improvements in new construction, (b) rehabilitation, (c) loss reduction programs, (d) risk analysis and the importance to various constituencies, along with imbedded tasks of importance in each case. This paper relates the issue descriptions to current federal guidelines and points to requirements for stakeholders and other constituencies.

Thermopastic Composite Structural Insulated Panels (CSIPS) for Building Construction

by N. Uddin, A Vaidya, and U. Vaidya

The authors reported on some of the latest research on structural insulated panels as might be used in special construction. In these studies thermoplastic skins were employed and showed overall significant strength enhancement with three-point loading, although some face sheet components experienced cracking. Clearly more research is needed for this valuable product to meet distortion standards, which might be needed for major disaster protection.

A New Mitigation Strategy—The Tennessee Multihazard Mitigation Consortium (TMMC)

by James E. Beavers

This paper describes the planning and formation of the Tennessee Multihazard Mitigation Consortium (TMMC), a model not only for Tennessee but also for other states as well. Approved in principle at many levels, TMMC awaits state legislative authorization and appropriation status. It coordinates the activities initially of three institutions but is expected to grow to be a major resource and formal action center for many kinds of disasters in the state of Tennessee. This document describes how a fully focused (broad in scope) institute can be developed and serve as the focal point for mitigation action.

How Communities Implement Successful Mitigation Programs: Insights From the Multihazard Mitigation Council (MMC) Community Study

by Elliott Mittler, Linda Bourque, Michele M. Wood, and Craig Taylor

In this paper the authors describe the findings of an ATC congressional mandated study on successful mitigation efforts by nine U.S. communities of various sizes. For each city the authors describe what mitigation measures were addressed and how leadership factored into the effort. It contains valuable information on subsidizing mitigation measures and the final result.

Achieving Risk Reductions in Critical Infrastructure Systems

by Richard G. Little

This thought provoking paper discusses risk reduction from the broad perspective of the string of critical infrastructure that must be operative to maintain our economy. The theory is simple and expressed in understandable terms, but more importantly, the author discusses of the consequences of non-functional infrastructure.

The Unknown Seismic Hazard in East Tennessee and Potential Losses

by Christine A. Powell and James E. Beavers

This paper presents a mini history of the seismicity in Tennessee (major earthquakes in 900, 1450, and 1811-1812) with particular attention to eastern Tennessee. The authors point out that eastern Tennessee is quite active seismically, and that such seismicity needs more attention by those responsible for national, state, and local codes and regulations to mitigate potential damage through economical means.

Frequency of Hailstorms and the Resulting Damage in the Central United States

by Douglas L. Dewey and Rosemarie G. Grant

Authors Douglas Dewey and Rosemarie Grant have prepared a landmark summary contribution on the hazard of hailstorms and the damage potential (risk) associated with it. Among other valuable discussions contained therein is a section on the true impact of hail, which provides interesting insights on current insurance coverage of wind and hailstorm damage. The paper also discusses resistance parameters and case histories.

Resources

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A Changing Perspective—Major Challenges

William J. Hall[1]

Introduction

Our professional mandate is clear: First, we need to define meaningful research and development on the role and significant design parameters of importance with respect to the effects of multiple hazards on a full range of infrastructure projects, and second, to explore methods of integrating design related protective measures into the construction of such projects. In this way, loss of life and major casualty losses can be reduced over time.

The symposium centered on (1) identifying issues and reviewing what has been accomplished to this point in time (2006) with respect to multi-hazards, (2) assessing where we stand with respect to new ideas relating to developing appropriate design criteria for a wide range of natural hazards, as well as perhaps some related man-induced hazards, and (3) how best to integrate this material into infrastructure construction practice. In approaching these goals we recognize that politics, funding, and national and local perception of need, along with federal, state, and local regulations, as well as a range of professional issues, including those of contractors, need to be addressed. All of the latter requires much time, effort, and leadership.

The world at large still looks to the United States for guidance and leadership in design-build matters. We must strive to maintain top-level leadership in our respective disciplines and remain leaders rather than followers. Many changes are badly needed. To this end, within the fields surrounding multiple and man-induced hazards, we need to sharpen our skills as described in the adage "observe, listen, think, and act."

Rather than brushing over all aspects of the multitude of topics covered by the symposium's title, this paper focuses specific comments and suggestions on four major issues:

1. The multi-hazards (natural and in some cases man-made issues)
2. The challenges of quantifying and explaining (selling!) formal risk assessments as well as some thoughts about possibly broadening such coverage
3. Mitigation measures
    - design, analysis, construction and inspection
    - codes, guidelines and margins
    - engineered and non engineered infrastructure

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4. Education and training
    - role of advanced education and training.
    - goal in the infrastructure design/analysis and construction process to make it "automatic" to consider multi-hazard features so as to provide increased but economical protection to society.

The Hazards

Examples of commonly recognized natural hazards include landslides, avalanches, earthquakes, tsunamis, volcanoes, wildfires, floods, tornados, hurricanes and high winds, severe rainstorms, snow and ice, and the list goes on. Under each of the descriptive effects there are many other severe effects as well. For example, for earthquakes there would be shaking, faulting, changes in landform, liquefaction, and such.

In dealing with multi-hazard guidelines and design-related documents, the hazards need to be well defined, as they would be structured in a performance design document. Why a performance document? In dealing with a host of hazards, the first documents needed (some already exist in part) are those providing performance information to develop important design parameters taking into account anticipated commonality of details. Specific deterministic/probabilistic computational design aids would follow. However, with the changes in the form and severity of the hazards that seem to be occurring worldwide, these documents and procedures must be adaptable to change. Some obvious examples of changes include the frequency and size of hail (baseball size with immense destructive power); global warming effects on such things as permafrost and changes in storm severity; seemingly more serious wildfires as zones of tender increase in size and dryness; warmer ocean waters leading to stronger and increased number and severity of hurricanes and typhoons; increased occurrence of rain deluges; and the ability to better predict likely earthquake zones. What should we be doing in these areas to do better? We must work to define the hazards as fully as possible, with best estimates of extremes and probable likelihood, but we must cast the effects in such manner that the parameters are readily adaptable to change as needed and easy to handle in the design/build process.

Other related hazards of a different nature are an important part of the natural ones. For example, the earth's population continues to increase, and this factor leads to changes in the atmospheric properties and ocean characteristics, unwise land development, rescue factors, pollution, lack of food and potable water, along with accompanying famine, diseases of many types, the possibility of war, lack of ability to provide financial or humanitarian help as needed, and the list obviously goes on. And increasingly in recent years there are numerous man-made factors of concern, for example those associated with terrorism, blast, shock, and possible dissemination of toxic and nuclear materials.

Quantifying and Explaining Risk Assessment (for multiple hazards)

The theoretical modeling tools and analysis techniques for risk assessment are constantly being refined. In light of the many societal factors surrounding natural and man-made hazards, modeling tools should include many factors other than solely the intensity and return period of an earthquake or hurricane at a given location. In the case of a hurricane, these other factors might include displaced people, famine, disease, and maybe even rescue, food supply, and medical care. The goal should be to arrive at an assessment that provides a comprehensive picture of the risk (and amelioration issues!) covering a broad spectrum in order to aid in the best manner possible the local, state, federal, and private governing and emergency services entities. How inclusive should a risk assessment be?

Another major task concerns analysts' ability to convey risk findings in a simple and understandable manner that can be easily and quickly understood (the selling task). This immensely important aspect of risk assessment needs major work accompanied by education and training of students and professionals. Usually risk assessors are qualified analysts with minimal training in how to convey their findings to corporation executives, and other decision-makers who often have limited or no training in higher mathematics or in probability reasoning. In summary, improvement of many aspects of risk-related education and application are badly needed.

Another shortcoming in risk assessments is that of developing findings that include *margins* reasoning, which in turn serves to describe bounds (with definitive explanation of meanings) on estimates given. Training in this aspect of risk assessment would be appropriate and helpful in interpretation.

Mitigation Measures and Codes and Standards

Normal planning and design involve the use of codes and standards, as well as good judgment; it normally takes one generation or more to incorporate changes in these documents. Mitigation measures for multi-hazards can be provided at the time of initial construction or possibly through later upgrades; however, the most cost-effective measures are incorporated at the time of initial design. Thus, there is a need to develop guidance literature for architects, engineers, and the homeowner, and even to provide contractors detailed information on multi-hazard mitigation measures.

Multi-hazard treatment will eventually involve new performance guides, supplemented with specific design codes and standards. Today's codes and standards have become overly prescriptive to the extent that the designers (the users) are unable to understand or detect the reasoning behind the provisions and, thus, are unable assess their adequacy. With more attention to performance documents some of these difficulties should disappear, but overall there is a need to make the codes and standards simpler and easier to follow.

In the same vein, we should remember that while codes and standards are necessary for good design practice, they are often insufficient. This underscores the need to understand the basis of design provisions, to keep abreast of advancements and better practice in the field, and to develop better materials to achieve these goals.

Identification or discussion of strength and deformation margin effects is almost totally absent from existing building codes, standards, and guidelines. Definitive treatment of margins of safety, coupled with information on deformation and strain limits, and in guidelines, standards, and codes can lead to better design, especially by engineers who have had little or no exposure to these issues in testing laboratories. An excellent way to handle margins as a topic would be to incorporate a section of the code/specification/guideline to structural performance, where it could be addressed easily. Many aspects of design for multi-hazard effects serve to increase protection against man-made effects as well.

The treatment of non-engineered infrastructure is cause for increasing concern. Universities are providing instruction only for engineered construction. This seems to be a questionable practice for which we could be faulted. The largest casualty losses of property and lives generally occurs with non-engineered infrastructure, where typically not even architects, much less engineers, are involved.

Education and Publications

There seems to be growing consensus that the professional entry-level for engineers should be a master’s degree or equivalent rather than a bachelor’s degree. This makes sense, especially as pressure continues on moving the graduation hours downward for the bachelor’s degree. With an advanced degree, depending on specialization, the student has more time for technical subjects, as well as some general topics such as management and financial courses. With respect to multi-hazard matters, additional education and training should enable the engineer to incorporate multi-hazard design details into a design, almost without thinking and with slight cost changes (if any) involved.

Conclusion

The subject of multi-hazard design is important, along with follow-through in construction practice; documents to support this effort are needed badly. The challenge is to develop a cadre of leaders who can formulate a coherent program of investigation and move forward with the effort required. If history repeats itself, we can expect 15 to 25 years of effort—a generation—to precede any significant changes in the documentation to accommodate multi-hazard design and construction. In the interim we can be assured that remedial measures will appear, some of merit. Hopefully all treatments will be simple in form and understandable.

One day one of my early employers came in at 4:45 pm and explained the great need to execute an important task promptly and after a period of silence said, “If nobody does anything, nothing will happen!—pause—We need that task done NOW.” Needless to say, it turned out to be a late night! Similarly here, we need leaders with a plan, leaders who can see that the proper (quality) work follows, and leaders who will know how to execute adoption over time.

I feel confident that multi-hazard design/construct practice will be a reality in the future, hopefully in the near future.

The Context for Successful Loss Reduction from Natural and Technological Hazards as Applied to the Central and Eastern United States

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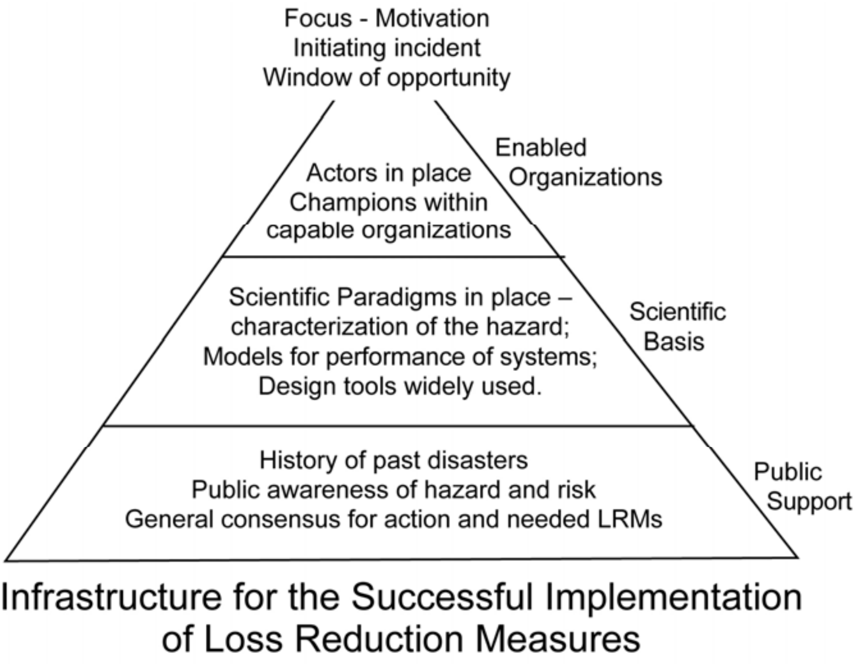

Figure 3.1. Context for Successful Risk Reduction Programs

Overview

There have been many programs for the reduction in losses from natural and technological (man-made) catastrophes. The success of loss reduction measures (LRMs) is context-dependent. *Context* here refers to the elements of time, place, and situation that surround an event. Elements are technical and human, political and economic, scientific and psychological. We wish to explore the "context" needed to design and implement successful loss reduction programs.

Some of the questions we face are:

- What can be done to effectively motivate disaster mitigation programs?
- What does it take to encourage groups to engage in mitigation for natural and other hazards?

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- What was the context for disaster mitigation programs successfully implemented in the past?

Figure 1 illustrates the context for success. LRM programs require a broad base of public support. We need the scientific basis—characterization of the hazard and tools for analysis and design,—together with specific measures (LRM) shown to be effective. Champions must be in place within enabled organizations so that when an incident opens a window of opportunity they can act.

The following sections explore issues surrounding the successful implementation of loss reduction programs. No two loss reduction programs are alike—the context is unique for every program—but successful programs of loss reduction address and manage these elements well, so it pays to be aware of these issues and design flexible programs.

Two types of loss-reduction process seem to be at work:

- incremental changes occurring more or less routinely, applying to new construction; and
- initiatives to rehabilitate the existing built environment precipitated by dramatic events (such as hurricanes, earthquakes, tsunamis).

We may divide the discussion along these lines.

Incremental Improvements in New Construction

Gradual, incremental improvement occurs in the disaster resistance of the built environment:

- with new provisions in building codes;
- with changes in zonation and land-use planning to keep people and property out of harm's way;
- with mandatory upgrades triggered by change of occupancy or re-roofing, as new materials and analytical models are developed, and such; and
- with "prudent owner actions" from voluntary of risk management programs.

Improvements in technical capabilities and the safety infrastructure (the system to design and construct safe facilities) are other examples, with better inspection and enforcement, improved materials and construction methods, and such.

These low-key changes go on without fanfare, but may be more effective in gradually creating a more disaster-resistant community than the large programs that try to remedy deficiencies in the existing built environment.

These gradual improvements may be offset by accelerating development in hazard-prone areas, with the result that the human community faces greater aggregate risk over time, rather than less.

Question: What is the context for successful implementation of incremental changes in new construction? This seems to occur without dramatic revolution.

Rehabilitation Programs

When a disaster strikes, such as Hurricane Katrina, with large-scale impact on people and property, programs may be initiated to remedy the perceived weaknesses and render the community more resistant to future, similar events.

A prepared and equipped engineering and construction community, an informed public, and a whole chain of circumstances are needed for successful implementation of loss-reduction measures to protect humans and their planet from natural and technological hazards. By themselves:

- models to assess risks are not enough;
- a list of consensus LRMs and their effectiveness is not enough;
- an event is not enough (for example, earthquakes in Charleston, SC, 1886, San Francisco, CA, 1906; Santa Barbara, CA, 1925, and Landers, CA, 1992);
- active proponents within private and public organizations are not enough; and
- commissions and councils are not enough.

It is clear that an entire infrastructure is needed for loss reduction, and a consensus for action—before any program can be successful. The economy needs to be healthy enough to absorb the costs of loss reduction. Well-conceived, achievable programs need to be proposed. Finally, the implementation of loss reduction actions usually requires some emblematic event to occur, widely covered by the media, with unacceptable human consequences, to galvanize public awareness, harness the political will, and motivate legislation or other vehicles for change.

Question: Will the political momentum generated by the losses in Hurricane Katrina and the resulting public outrage be able to overcome the endemic poverty and past inadequacies in local design and construction practices so that rebuilding can be successful?

Champions

Much has been written and discussed about the important role of champions or advocates in motivating the inception and execution of mitigation programs within governmental and business organizations (for example, FEMA 474; also Taylor, Craig, Elliott Mittler, and LeVal Lund 1998). The discussion has pointed to various ways we can motivate and equip such champions, for example former Senator Al Alquist on earthquake safety in California or Vice President Al Gore on global warming.

Taylor et al (cited above) caution that champions may come and go, and LRM programs that depend on champions may in turn succeed and fail. Others [Y. Wang, DOGAMI) suggest that a champion's initiative can be institutionalized—captured and perpetuated within an institutional environment.

The Role of Disasters and Windows of Opportunity

Again, much has been written and discussed about the role of actual disasters in garnering public attention and in forging the political will and consensus for governmental expenditures, new legislation, and such to reduce the vulnerability of communities at risk. Some of these studies recommend preparation of plans for change to be implemented when a disaster opens the proverbial window of opportunity. Chance favors the prepared. For example, the Missouri State Emergency Management Agency (SEMA) used post-disaster FEMA Mitigation Funds and the Missouri Department of Economic Development's Community Development Block Grant Program (CDBG) together with HUD funding to fund the 70 communities conducting voluntary buyouts of primary residences to help citizens move out of the floodplains. According to Susie Stonner of SEMA, the buyout land became the property of the community. Deed restrictions disallowed future building on the buyout lands.

SEMA and CDBG worked with the 70 communities to move residents out of the floodplains. The concept was simple. The communities used state and federal funds to purchase primary residences in the floodplains from voluntary sellers. The properties were appraised at pre-flood value less disaster assistance claims. Once the local communities purchased the properties, the land was turned into open spaces or parks for community enjoyment. Approximately 4,200 parcels of land were acquired.

Stonner relates that the communities of Rhineland and Pattonsburg moved their towns out of the floodplains. The village of Wakenda dis-incorporated (with the land reverting to farms), and the village of Lupus elevated 11 structures on the Missouri River. Many of the same areas flooded again in 1995, without loss to the relocated town residents.

It is interesting to note that local disaster creates local opportunity; national-scale disaster creates larger opportunity. Television and electronic media have evolved, and public response has evolved so that media coverage and public attention span are a moving target. Global coverage of worldwide disasters has desensitized the public to disasters. We see them constantly wherever they occur, all over the world.

Forms of Successful Loss-Reduction Programs

Disaster mitigation projects and programs come in many forms:

- changes in codes and new regulations
  - new provisions to improve the disaster resistance of buildings, lifeline and utility structures
  - land-use planning measures
- changes in inspection and enforcement
- new standards and guidelines (FEMA, TCLEE, ALA, others)
- voluntary programs
  - residential
  - commercial
  - governmental (such as earthquake retrofits of city halls, fire stations, schools)

- subsidized governmental programs (such as FEMA mitigation grants) for public agencies
- mandatory mitigation programs
  - retrofit ordinances
  - retrofits triggered by changes in occupancy, substantial additions, or renovations
- programs by financial institutions—lender or insurer requirements
- active loss-control functions—inspections and loss-control punchlists

Yet to explore: How does the type of program typically relate to the type of peril?

The Role of Risk Analysis

We are faced with terrorism, war, disease, pollution, earthquakes, tsunamis, hurricanes, large volcanoes and other terrestrial natural disasters, and rare extraterrestrial threats from asteroids and comets. Slowly, the globe is warming, weather patterns change, and global sea levels rise. Overpopulation taxes the earth's rare resources, and humans crowd out and poison other species. Forests disappear and deserts take their place.

How do we compare the risks of lives lost, economic impacts, and return periods between catastrophic events? How do we allocate resources and priorities? What research is needed, and how do we communicate results? Science and mathematics must respond. We need to use reliable risk analysis tools for rational comparison leading to better decisions than those generated by rhetoric from politicians or knee-jerk reactions from scare tactics.

Not all mitigation programs are worth the effort. Which ones are? How do we decide among all of the potential threats? What is the role of scientific studies and analytical tools such as HAZUS or other analytical/predictive models in the winnowing process to decide how we spend society's available resources?

Comprehensive Study—FEMA Loss Mitigation Programs

FEMA-61 explored some of these issues within the context of various FEMA programs for post-disaster assistance and pre-disaster mitigation. FEMA makes extensive use of benefit- cost analysis (BCA) technologies, and provides tools for applicants. Applications are reviewed in an annual process, in which the merit of the project is examined as well as the way in which estimates of benefit and cost were developed.

To date, FEMA BCA tools have been awkward, limited, and quite difficult to apply. Like any tool, they have been subject to manipulation, to the advantage of the clever applicant. These tools clearly influence the outcomes of which programs are funded. Proposals to FEMA often require large investments in consulting resources. The quality of presentation and conformance to FEMA protocols may overshadow the actual merits of an LRM proposal.

FEMA's rules for mitigation programs create a new set of obstacles for any public agency to overcome. For example, it is awkward to accommodate a program that combines repair and retrofit. Further, the Stafford Act has restrictions on the ways in which funding can be used.

The barrier of complying with FEMA procedures may prevent many public agencies from seeking loss-mitigation grants. FEMA (or associated state agencies) may wish to engage in pro-active loss reduction promotion, conducting high-level studies to identify candidate regions and agencies where loss reduction programs would typically pencil out. For these agencies, FEMA could send a representative to help them understand the opportunity and the procedures to seek a grant. These agencies could be pre-qualified; FEMA could streamline the procedures for them.

Mere Numbers May Not Motivate

When we use risk analysis as a tool to motivate change, we face a human psychological obstacle: Most of us do not feel a threat presented in terms of numbers. We feel a threat that is presented in terms of pictures and sounds of human suffering— the form of the evening news. (See Section 8, on the psychology of risk.)

Infrastructure for Risk Reduction

Successful risk mitigation initiatives, whether incremental improvements to reduce risks for new structures, or rehabilitation initiatives for the existing built environment, rely upon a solid infrastructure for safety. By infrastructure for safety we refer to all of the people and tools and materiel needed to design and construct safe structures (buildings and lifelines) within an environment that includes natural and technological hazards.

A chain is an apt metaphor for the system to deliver safe structures within the built environment, since a series of steps must be successfully accomplished for structures to perform safely under normal conditions, as well as natural or technological hazards. The chain of safety includes the following:

- adequate knowledge and definition of hazards;
- adequate codes and standards to address the hazards;
- appropriate design tools to quantify the effects of hazards on systems and components so that good performance can be designed in;
- qualified, skilled, and experienced engineers and designers;
- adequate budget, affording the time to effect a good design;
- adequate plan checking and effective enforcement of codes at the design stage;
- good materials, material suppliers, and material testing;
- skilled workers and conscientious contractors;
- adequate inspection and enforcement of codes during construction;
- active involvement of the design professionals during the construction process to resolve the problems of constructability; and
- adequate maintenance.

(Of course, it remains to define what we mean by adequate, qualified, appropriate for each of these elements.)

Without these elements, we cannot construct structures to resist natural or technological hazards, and we cannot engage in effective mitigation programs or initiatives. Where any one of these elements is lacking, problems occur, and higher damage may result in natural hazard events. For example, where hazards are not adequately defined (say, near an unknown active earthquake fault in the eastern United States), the built environment will not be adequately protected. It is when we recognize a weakness in one of these links after the fact—and the weakness is compelling enough—that rehabilitation measures are discussed, considered, and sometimes implemented.

Within the United Sates and the developed nations, we take this chain for granted in many ways. We assume that good materials are available, that codes are adequate, and that the engineering community is trained and qualified. This may or may not be true within the United States. In small towns, such as in the central and eastern United Sates, the fire chief may also serve as the building official, and adequate plan check or construction inspections may not be possible. In other areas of the world, the resources and systems needed to design and construct safe structures may not be present, limiting what can be done in new construction, and further complicating any initiatives to reduce hazards in existing construction.

Disaster Stakeholders and Constituencies

Disaster Stakeholders

In devising and promoting loss reduction, we must consider the particular stakeholders affected by the specific disasters or threat in question.

Kinds of Stakeholders

- General public
    - Homeowners
    - Landlords
- Private companies
- Public corporations
    - Large
    - Small
- Public agencies
    - Utilities
- Scientific and Engineering community
    - Research organizations
    - Consultants
- Governmental agencies
    - Public buildings and infrastructure

Yet to explore: How does the form of loss reduction program relate to the type of stakeholder?

Disaster Mitigation Advocacies

Each threat creates a community around the most affected stakeholders. We can refer to them as *disaster mitigation advocacies*. These responding communities are devoted to analyzing and responding to the threat, and their activity and size depends on the resources and tools available, within the context provided by economics, politics, and public sentiment. These communities clamor for and compete for public and private funding. Each threat community promotes the threat it addresses as warranting increased resources.

We should not blindly rely on the disaster mitigation advocacies to tell us where to best spend the money. We need a larger view, a way to measure risk in a balanced way for all threats so that public resources can be employed to the greatest public benefit.

Public Awareness and Risk Literacy

Human Psychology in Response to Threats

To carry out loss reduction programs, human agents must take action. Nature has not equipped humans for making good risk decisions within today's environment. The average person decides risk issues very poorly, on an emotional, intuitive basis. We react first through emotion. The common citizen does not understand or trust complex, technical tools for the analysis of disasters. We face a gulf between the technical community and the public.

Perception of Threat

Humans perceive threats and act on them using resources that evolved over millions of years. Humans are good at judging immediate or sudden threats in their local environment and acting quickly for self-preservation. Humans often do not perceive or act upon threats that evolve slowly, that may or may not affect their local environment (place uncertain), or which may occur at some undefined future date (time uncertain). Furthermore, individuals may abdicate personal responsibility and fail to take action when a threat is beyond their personal capacity to react or take effective individual action. Action by a group generally results from threat perception from the leadership of the group. Under certain circumstances (cases requiring specialized expertise for valid judgment), we may delegate to experts or expert panels the right to make certain judgments and decisions on our behalf.

The human psychological framework evolved under vastly different circumstances, unlike today's technological, urban environments. We do not evaluate exposure, hazard severity, and prospective consequence well, and our schools do not teach quantitative risk assessment. The average person is not educated and equipped to decide risk issues on a rational basis.

Threats are ordinarily perceived by the senses: sight, sound, touch (pain), smell, or taste. They must occur relatively suddenly for the human mind to register a difference in conditions and to impact awareness. When a risk is conveyed by numerical predictions produced by a complex mathematical model, the natural human reaction is no reaction: the threat simply does not register. This is far different from the experience of an actual event—an earthquake, flood, hurricane, tornado, or bad winter storm.

Mathematics, logic, and physical models provide a new sense that speaks in a language of numbers: losses and probabilities, severity and frequency, hazard, vulnerability, expected outcome, and confidence bounds. This language is foreign to anyone who did not complete several years of college with a mathematics and science curriculum. So 80 to 90 percent of the public is automatically excluded from intelligent discussion and understanding of the results of these models. Speaking to the public in these terms is just like speaking a foreign language unknown to your audience. You will make noises, and they will scratch their heads, and the public will learn nothing and take no action. We must translate the results from our models into more common human terms.

Sudden Change and Gradual Change

The human being is designed by nature to detect and respond to change. Unchanging patterns of activity and behavior are accepted without question. Slow or gradual change allows for accommodation and may not be perceived as change. A sudden initiating incident, distinct from the background noise and presenting some threat, is enough to get our attention and elicit a response. This is why a disaster has such a profound psychological impact.

With this in mind, successful mitigation of chronic, long-term threats may need to incorporate media events to promote awareness to sustain public support.

Response to Negative Stimuli

Contrary to what we would like to believe about human perception and decision-making, it is only partially objective and rational. Most often, perception is governed by automatic human programming—we are startled and duck when a large object moves at us quickly, we react to images of human suffering, cries, and blood. We keep away from those who are affected, and we avoid the impacted locations.

Disasters and suffering are negative stimuli, generating avoidance as the emotional response. The entire issue is avoided, including the potential remedies. It becomes difficult to induce a positive response (actions to reduce future loss) to a negative stimulus.

Public Awareness and Risk Literacy

Public awareness and risk literacy help to elevate the discussion from the emotional level to the rational level. Risks can be contrasted, and risk reduction alternatives can be brought forward, discussed, and compared in a logical way.

Role of Expert Panels, Councils, and Commissions

We rely on our leaders to formulate public policy to address general risks. Our leaders may (in their wisdom) call upon risk experts and scientific panels to provide the needed input for the formulation of good public policy. Too often, our leaders neglect this step in favor of the (uninformed) public opinion poll.

What is the role of expert advisory groups or panels such as the Seismic Safety Commission in California, or the Florida Wind Commission in Florida, or the Building Seismic Safety Council nationally?

Retirement of Loss Reduction Programs

How do we decide when an institutionalized loss reduction program is no longer needed? How do we provide for timely retirement of LRM programs to free up the resources for other, more urgent efforts? The programs may become a cause in and of themselves, with a constituency that resists their extinction.

Conclusion

Of course, the conclusion is that there is no conclusion. Successful loss reduction programs take advantage of many elements. The infrastructure for risk reduction—the technologies, professionals and institutions—must be built up and maintained. Practical loss reduction programs may be readied so that an initiating event (the next disaster) can motivate an aware and informed public to call for action and the government to carry out the prepared programs.

For the present, we offer issues and questions that may assist the conscientious policy-maker or loss-reduction champion in considering the many possibilities for initiating successful loss reduction programs. The path forward for any depends on the human, political, economic, and technological context.

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Thermoplastic Composite Structural Insulated Panels (CSIPS) for Disaster Mitigation Construction

N. Uddin,[1] *A .Vaidya,*[2] *and U. Vaidya*[3]

Structural insulated panels (SIPs) construction systems are rapidly revolutionizing the construction industry. These panels are easier to erect, result in better quality walls, and have excellent insulating properties. Traditionally, SIP construction consists of plywood or oriented strand board (OSB) as facesheet materials and uses molded expanded polystyrene (EPS) as core material. The issues with using OSB as sheeting includes poor impact resistance against wind-borne debris generated during high wind scenarios, heavy weight, mold buildup, and disintegration under floodwaters. To overcome these issues the OSB sheeting in the traditional SIP panels were replaced by thermoplastic skins in this study. This produces light-weight, composite SIP (CSIP) with high strength to weight ratio. Some aspects of the fabrication of the composite SIP panel are presented in this paper in conjunction with performance of SIP panels made from 1.60 x 10^7 Mg/m^3 (1pcf) and 4.80 x 10^7 Mg/m^3 (3pcf) density cores, with regards to baseline flexure, pull-out, edgewise compression testing, and high-velocity impact (HVI) testing.

Introduction

Structural sandwich composite panels are nowadays widely used in aerospace, marine, automobile, locomotive, windmills, building, and consumer industries (Hosur 2007). These structural sandwich composites are made up of two stiff, strong faces separated by a lightweight core. The core of these panels acts to separate the faces, increasing the moment of inertia of the panel with little increase in weight, producing an efficient structure resisting bending and buckling load (Moavenzadeh 1990). Structural insulated panels (SIPs) are high-quality engineered components that combine to form several important systems of a building (APA 1998). The core of SIPs can be made from a number of materials, including molded expanded polystyrene (EPS), extruded polystyrene (XPS), and urethane foam (U) (Morley 2000). These panels consist of EPS foam sandwiched between two sheets of oriented strand board (OSB). Advantages of using SIP panels are multifold. Large size panels are factory manufactured, which results in easy design, reduced construction time, and strong structure. There is practically no construction waste as would occur in traditional construction techniques. Greater sound and thermal insulation can be achieved using SIP panels, which result in the higher energy conservation (*www.r-control.com* 2006). The proven superiority in transverse and

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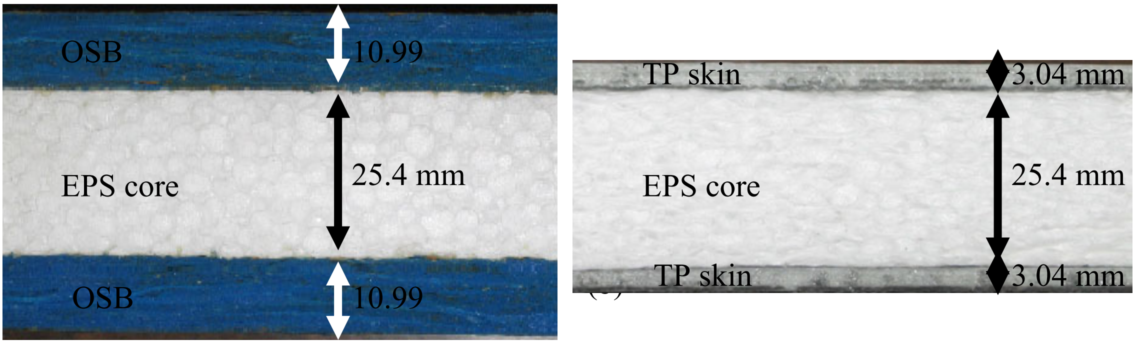


Figure 5.1. (a) Traditional SIP, (b) Proposed CSIP Panel

axial loading capabilities and increased racking resistance over conventional framing make SIPs a stronger, safer alternative (Morley 2000).

One of the major concerns with the traditional SIPs (Figure 5.1 (a)) is, however, that OSB has a tendency to absorb moisture and the faces swell if the edges are not sealed properly. Special treatments are required for traditional SIP panels using OSB skins to avoid mold build up on the wood, which can create unhygienic atmosphere and loss of millions of dollars in the flood prone areas. In addition to this in the events of hurricanes and tornados, the wind borne missiles generated by high-velocity wind can easily penetrate the OSB facesheets and, thus, can cause serious injuries to the occupants. Moreover, OSB facesheets can easily disintegrate under floodwaters.

To overcome these issues this paper illustrates the use of thermoplastic (TP) composites panels to replace the OSB sheeting in the traditional SIP construction (Figure1 (b)). Along with the weight savings, the thermoplastic skins are stronger and much thinner than the OSB faces used in the traditional SIPs. These faces also have better penetration resistance against wind-borne missiles during the events such as hurricanes and tornados. In addition to these advantages, the thermoplastic SIPs can be made attractive by adding coloring pigments to the facesheets while manufacturing them. This produces panels with uniform color and with better quality finish.

The baseline flexural testing test results of the TP SIPs are presented here. Limited description about manufacturing SIP panels is presented in of the first section of the paper. The final section compares the behavior of TP SIPs and traditional SIPs.

Literature Review

The main use of sandwich components in the construction industry is in building panels. Several manufacturers now produce wall, roof, and door panels using sandwich construction with different combinations of face and core materials. Typically the faces are made of steel, aluminum, or waferboard and the cores are made of foamed polyurethane, foamed polystyrene beadboard, or foamed glass. The foam gives excellent thermal insulation while the faces provide the structural stiffness and the strength of the panel. The panels are used in housing and in low-rise, nonresidential buildings such as fascia panels in commercial buildings (Moavenzadeh 1990).

Some of the earliest examples of sandwich panel technology can be found in the Usonian houses designed by Frank Lloyd Wright in the 1930s. Some of the walls consisted of three layers of plywood and two layers of tarpaper as structural elements (Morley 2000). In 1950 Alden B. Dow, an architecture student, developed a structural panel with an insulating core and was credited with producing the first SIP. His early houses were built in Midland, MI, using panels composed of 41.27 mm (1 5/8 inch) Styrofoam core and 7.93 mm (5/16 inch) plywood facing for load-bearing walls (Morley 2000). The first significant manufacturing effort came in 1959 when the Koppers Company converted an auto production plant in Detroit into a SIP production facility. Their method involved blowing pre-expanded Styrofoam beads between two sheets of plywood and bonding them with steam to the facings, which were already glued to a solid supporting framework (Morley 2000). OSB is an engineered wood product that has been extensively tested and found to be suitable for use as a load bearing material. In addition, it is readily available in the large sizes required by the SIP industry.

Building with SIPs generally costs about the same as building with wood frame construction, because of shorter construction time, less jobsite waste, and labor savings. The energy costs can be reduced by up to 50 percent by using SIPs as the construction panels. Because SIPs create a tighter building envelope than conventional insulation, the builder can actually reduce the size of heating and cooling equipment (www.sips.org 2007).

Manufacturing of SIP

Traditional SIPs. The OSB sheetings are adhesively bonded to the foam core for manufacturing of SIPs. These adhesives are water based and solvent free and do not have a negative impact on the environment.

The manufacturing of traditional SIP is a three-step process. First, the bottom facing is laid out in the assembly area. The desired core thickness pieces are run through the glue-spreading machine, where the adhesive is applied to both sides of the core pieces. These core sections are placed on the bottom facing, then the top facing is positioned. The assembly is aligned before being moved into the press (Morley 2000). After removal from the press, the SIP are cured in place for 24 hours before being moved to a storage area.

TP CSIPs. Traditionally the facesheets of SIPs consists of 11.11 mm (7/16 inch) OSB sheets, which were replaced by thermoplastic panels in this study. After rigorous calculations and finite element (FE) modeling, the equivalent thickness of the TP skins was determined to be 3.04 mm (0.12 inch) to achieve equivalent stiffness and load bearing capacity as 11.11 mm (7/16 inch) OSB. The facesheets of the TP CSIPs considered in this study consist of 70 percent bi-directional glass fibers impregnated with polypropelyne (PP) resin and the core consists of EPS foam.

The pre-form of the glass/PP is manufactured using a hot melt impregnation technique in which the glass fibers are passed through the PP resin chamber. The impregnated fibers from the resin chamber are then transferred to the chiller section where they are cooled and then sent to the cutter. The tapes of desired dimensions are cut in the cutter section. These tapes are then woven in a crisscross pattern to achieve a bi-directional orientation. To achieve the desired thickness, the woven preform layers are pressed in the compression press at the desired temperature. In this study, however, the 3.04-mm (0.12-in.) thick panels were directly obtained from the manufacturer.

During fabrication the facesheets are bonded to the core with a film adhesive. The bonding process details are proprietary and are not included in this paper.

This manufacturing method is fast and less labor intensive than manufacturing traditional SIPs. In addition, this manufacturing technique can produce high-quality, attractive panels quickly. The weight comparison of the traditional SIPs and the TP CSIPs are presented in Table 5.1.

Table 5.1. Weight Comparisons of Traditional SIPs and TP CSIPs

Sandwich details	Dimensions (Length x Width x Thickness) (mm)	Weight (g)
1.60 x 10^7 Mg/m^3 (1pcf) foam + TP skins	609.6 x 76.2 x 31.49	382.5
1.60 x 10^7 Mg/m^3 (1pcf) foam + OSB skins	609.6 x 76.2 x 47.62	701.5
4.80 x 10^7 Mg/m^3 (3pcf) foam + TP skins	609.6 x 76.2 x 31.49	408.4

Testing of SIPS

Testing equipment. The SIPs were tested under a three-point loading condition using a span of 558.8 mm (22 in.). A Tinius-Olsen Universal Testing Machine (capacity 27,215 N [60,000 pounds]) was used for flexural testing. The test setup was done according to ASTM C-393 (ASTM 2000). A crosshead moving rate of 7.62 mm/minute (0.3 inch/minute) was selected for the test. A linear variable displacement transducer (LVDT), which can measure a maximum deflection of 150 mm, was used to measure the deflection of the crossheads. Uniaxial strain gauges with a gage factor of 2.085 were attached to the bottom face of the panels at the geometric center to measure the transverse tensile strain produced due to the bending loads.

Behaviors of SIPS Under Applied Flexural Laoding

Behavior of traditional SIPs. The traditional SIPs were tested under three-point flexure loading on the setup noted above.

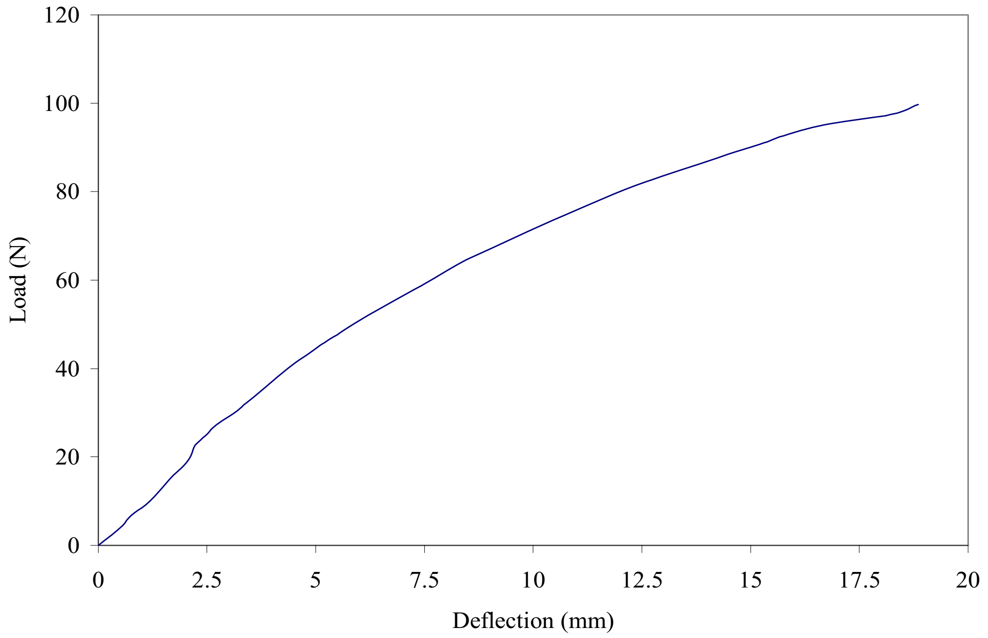


Figure 5.2. A Typical Load Versus Deflection Curve for the OSB SIP

It was observed that there was a gradual increase in the load until the panel reached peak load. The average peak load attained by OSB SIP panels was 97.6 N (220 pounds), and the corresponding deflection for the peak load was 18.8 mm. A typical load versus deflection curve for OSB SIPs is shown in Figure 5.2.

Shear cracks developed in the foam core once the load exceeded 27 N (65 pounds) and the facesheet on the tensile face of the panel started crushing. Figure 5.3 shows the damage conditions of the OSB SIP panels.

Behavior of thermoplastic CSIP. To compare the behavior of the traditional SIPs with the proposed SIPs, thermoplastic SIPs were tested under identical boundary conditions and loading rates. Two sets of panels were tested in TP SIPs. One set included panels with a core density of 1.60 x 10^7 Mg/m^3 (1pcf), while the second set included panels with a core density of 4.80 x 10^7 Mg/m^3 (3pcf). Three samples of each type were tested, and the mean results are reported in this paper.

Panels with 1.60 x 10^7 Mg/m^3 (1pcf) core density reached an average peak load of 30 N (65 lbs.), and a corresponding average deflection of 38.1 mm was recorded. A linear elastic behavior was observed until a load of 27.21 N (60 pounds) was reached. Shear cracks developed in the foam core once the load exceeded 27.21 N (60 pounds) as seen in Figures 4 and 5. These cracks were observed at 45Enear the support. The facesheets were seen to be intact, and there was no sign of delamination between the core and the facesheets.

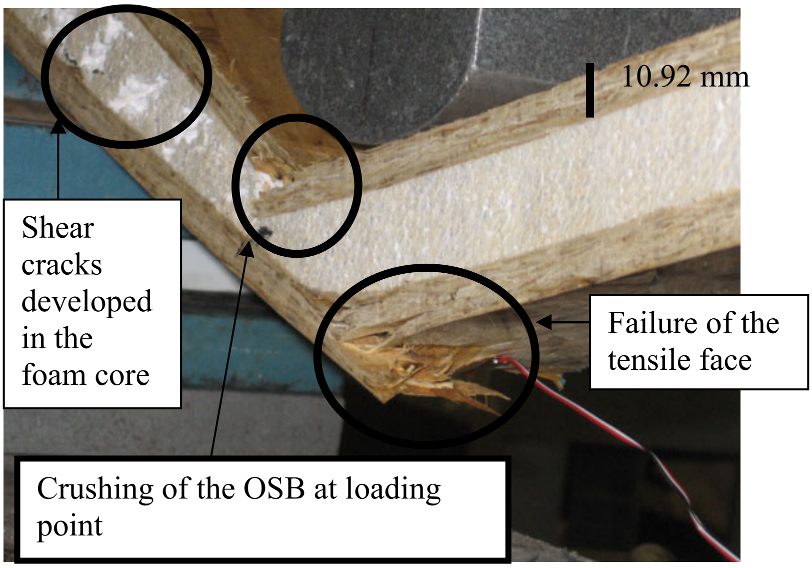


Figure 5.3. Failure of the OSB SIPs

There was an average permanent deformation of 6.35 mm observed for these panels during testing.

Shear failure of the foam core was observed as the mode of failure for panels with 4.80 x 10^7 Mg/m^3 (3pcf) density panels as observed in the panels with 1.60 x 10^7 Mg/m^3 (1pcf) core density panels. The average load carrying capacity of the SIPs with 4.80 x 10^7 Mg/m^3 (3pcf) core density, however, was 80 N (173.3 pounds), which is three times more than the SIPs with 1.60 x 10^7 Mg/m^3 (1pcf) core density. This can be correlated with the shear strength of the two different density foams used in this study. The shear strength of the 4.80 x 10^7 Mg/m^3 (3pcf) foam was 0.81 MPa, which was 385.71 percent greater than 0.21 MPa for 1.60 x 10^7 Mg/m^3 (1pcf) density foam. This greater strength increases the load carrying capacity of the 4.80 x 10^7 Mg/m^3 (3pcf) foam by almost three times.

Because of the higher degree of compaction of the core of 4.80 x 10^7 Mg/m^3 (3pcf) density, the foam below the point of contact squeezed completely, leaving a permanent indentation of 25.4 mm below the point of contact.

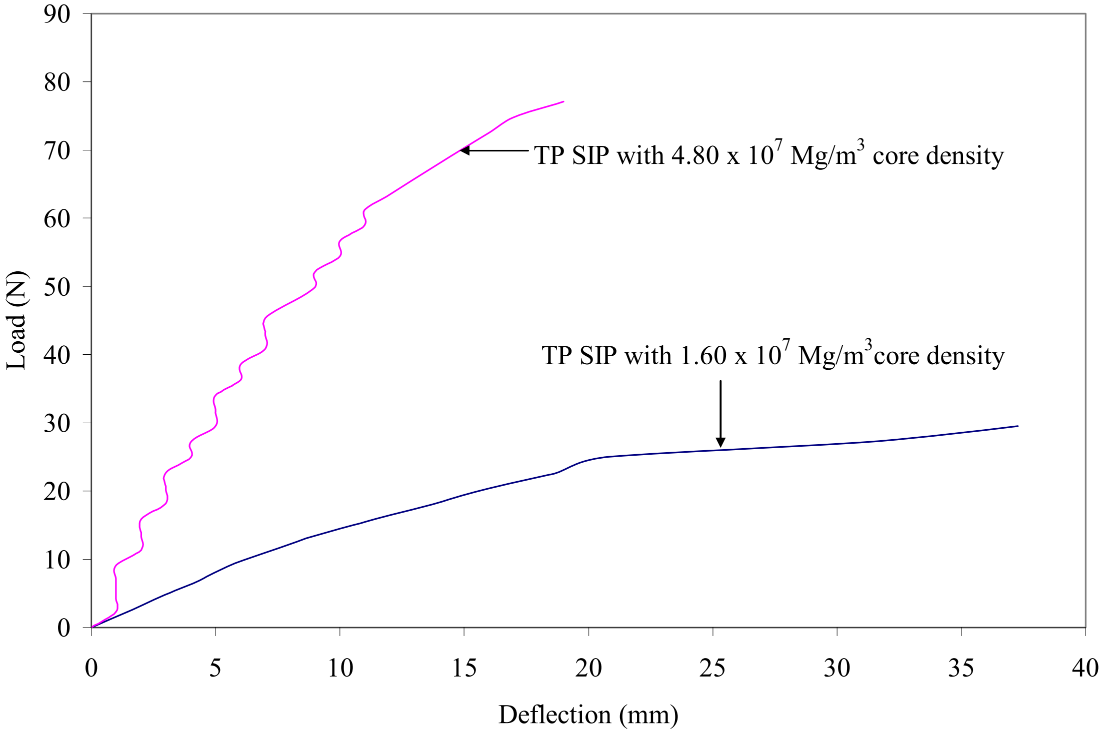


Figure 5.4. Typical Load-Deflection Curve for TP SIPs

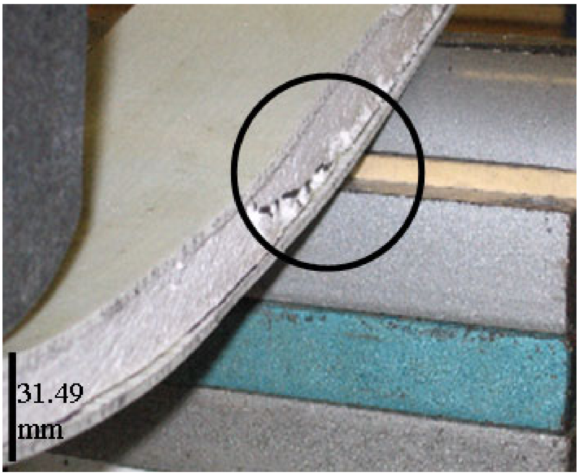
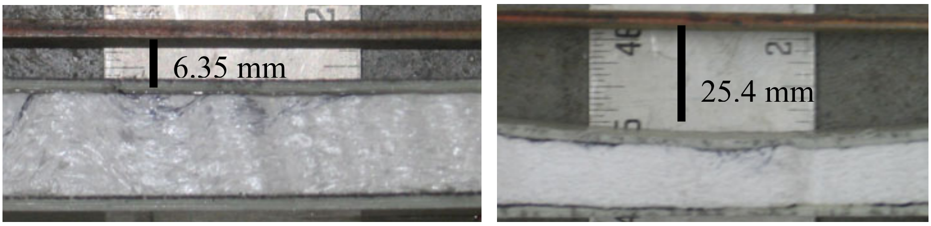


Figure 5.5. Failure of TP SIPs



(a) (b)

Figure 5.6. Permanent Set of SIP Panels (a) 1.60 x 10^7 Mg/m^3 (1pcf) foam, (b) 4.80 x 10^7 Mg/m^3 (3pcf) Foam

Comparison of Behavior of Traditional SIP and TP CSIP. Traditional SIPs and TP SIPs with the core density of 1.60 x 10^7 Mg/m^3 (1pcf) are compared for their response under flexural behavior. Stress versus strain values are normalized with the weight of each type of panel. Since the formula for finding the bending stresses is developed for beams whose material is homogenous, this formula cannot be applied directly to determine the normal stress in a composite beam (Hibler 1997). This formula can, however, be used by transforming the composite section into the section comprising of a single material. This can be done using transformation factor *n.*

$$n = \frac{E_1}{E_2} \tag{1}$$

Where E_1 and E_2 are the elastic modulii of the materials of the composite beams. The moment of inertia of the single material section can then be obtained, which can be used for finding the maximum bending stress.

In this study the bending stresses were obtained using the approach of transformed section, and the stress values are normalized with the weight. The values are plotted in Figure 5.7.

The average ultimate failure load attained by SIPs with OSB skins was 100 N, and that of the TP skins was 30 N. Though the load carrying capacity of the OSB SIPs was higher, there was a weight penalty of 183.3 percent for the same. The TP SIPs deflected up to 35 mm at the load of 30 N, while the OSB SIPs deflected by 3.4 mm for the same load making them much stiffer as compared with the TP SIPs.

The elastic modulus of the SIPs with OSB faces was found to be 1.52 x 10^3 MPa, while the elastic modulus of the TP SIPs was 2.265 x 10^3 MPa. It can be shown from Figure 5.7 that a stiffer configuration can be obtained once we normalize the stress by weight of the panel. This stiffness is due to the difference in the damage tolerance of the OSB and TP skins. As seen from Figure 5.7 in the case of OSB SIPs, the facesheets were seen to have fractured on the tensile as well as on the compressive side of the panel. Delamination was observed between various layers of OSB, which induced the cracking of the facesheets. Along with that the foam was also seen to have developed shear cracks. In contrast for

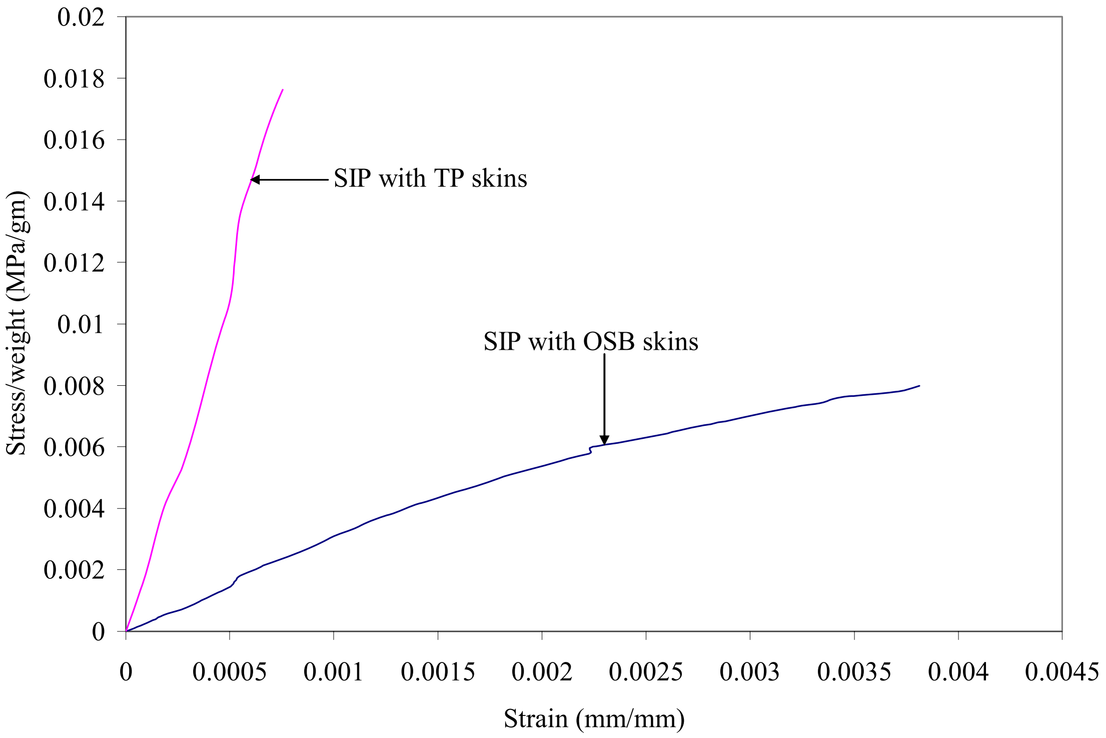


Figure 5.7. Normalized Value Comparison for Traditional and TP CSIPs of 1.60 x 10^7 Mg/m^3 (1pcf) Core Density

TP SIPs, the TP skins were seen be intact on the tensile as well as compressive side. The foam core was seen to have developed shear cracks as seen for the OSB SIPs. Thus, the SIPs with TP skins were seen to be more damage tolerant than the OSB SIPs for the applied flexural loads.

The OSB facesheets in the traditional SIPs failed in a brittle manner. The failure was sudden. As against that for TP CSIPs, the failure of the panel as a whole was gradual and a high degree of ductility was observed.

There was no sign of delamination between the core and the faces for both types of SIPs. Thus, the adhesives used for manufacturing the OSB SIPs as well as TP SIPs provided excellent bonding between the core and the faces.

HVI on CSIPs

Flying debris referred to as windborne missiles can cause severe damage to building structures. If wind speeds are high enough, missiles can be thrown at a building with enough force to penetrate windows, walls, or the roof. For example, an object, such as a 5.1 cm x 3.2 cm (2” x 4”) wood stud weighing 67 N (15 lbs.), when carried by a 112 m/s (250 mph) wind can have a horizontal speed of 44.7 m/ s (100 mph) and enough force to

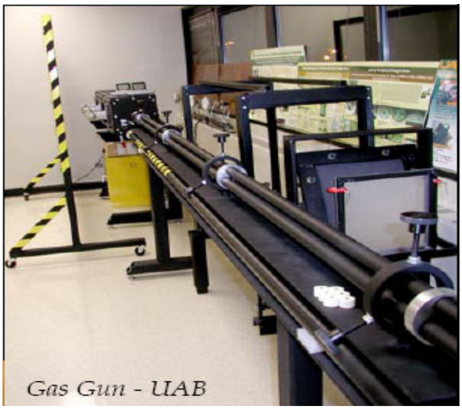
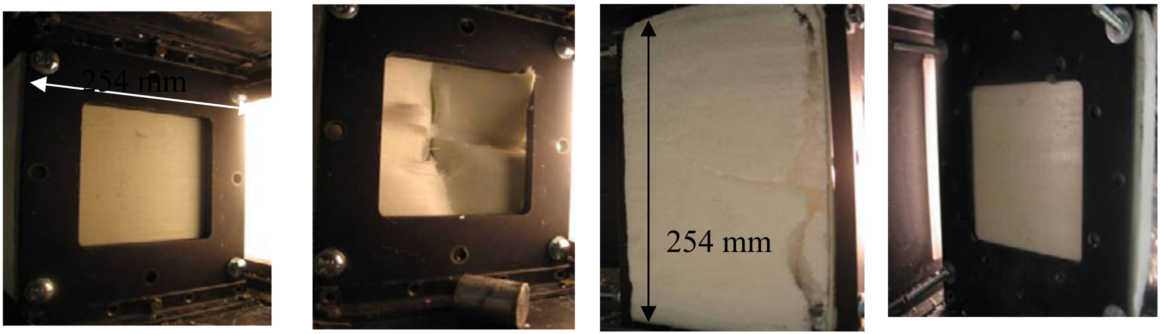


Figure 5.8. Gas Gun Facility at UAB

penetrate most common building materials used in houses today. Even a reinforced masonry wall will be penetrated unless it has been designed and constructed to resist debris impact during extreme winds. Because missiles can penetrate walls and roofs, they threaten not only buildings but the occupants as well. In this study the CSIPs are tested for their suitability for the high-velocity impact (HVI) scenarios. The results are compared with the traditional SIPs with the equivalent stiffness.

The HVI was generated using a laboratory-scale gas gun. The study was based on a standard developed by Texas Tech (FEMA 2000), which made use of an energy-balance equation to calculate the equivalent energy of impact recommended by Federal Emergency Management Agency (FEMA) (FEMA 2000) for the design of storm shelters against high-velocity wind. Using this energy balance, the velocity required for a gas gun sabot to produce the same amount of energy as a 66.7 N (15 lb) wood 5.1 cm x 10.2 cm (2 inch x 4 inch) traveling at a speed of 44.7 m/ s (100 mph) can be achieved using a 5.1 cm (2 inch) long, 3.8 cm (1.5 inch) diameter aluminum sabot traveling at 291 m/s (652 mph). Based on this study, the CSIPs were tested under the HVI using a blunt object impactor. The impactor was a 5.1 cm (2 inch) long, 3.8 cm (1.5 inch) in diameter 6061 grade aluminum sabot. The equipment used for generating the HVI is shown in Figure 5.8. The velocity of travel was 270 m/s (600 mph) to produce an equivalent velocity of the 66.7 N (15 lb) wood 5.1 cm x 10.2 cm (2 inch x 4 inch) traveling at a speed of 44.7 m/s (100 mph). The samples were sandwiched between the two steel plates and were secured with the help of bolts. This boundary condition was a typical wall where the wall panels are constrained along the edges.

Figures 9 (a-d) show the undamaged and the HVI tested CSIP panels. Whenever a panel is subjected to impact loading, the panel undergoes flexure with the bottom facesheet subjected to tension and the top (impacted) facesheet subjected to compression. This flexing helps the panel to absorb large amount of impact energy. This flexing depends on the ductility of the panel being tested. If the panels being tested are rigid, the failure is by a brittle manner, and the impactor would punch through the panels. The major mode of failure in this case was fiber breakage of the impacted facesheet.



(a) (b) (c) (d)

Figure 5.9. HVI on Full Scale CSIPs
(a) CSIP before impact, (b) Impacted face of the CSIP, (c) Side view of impacted CSIP showing cracked foam, (d) Intact back face of the impacted CSIP

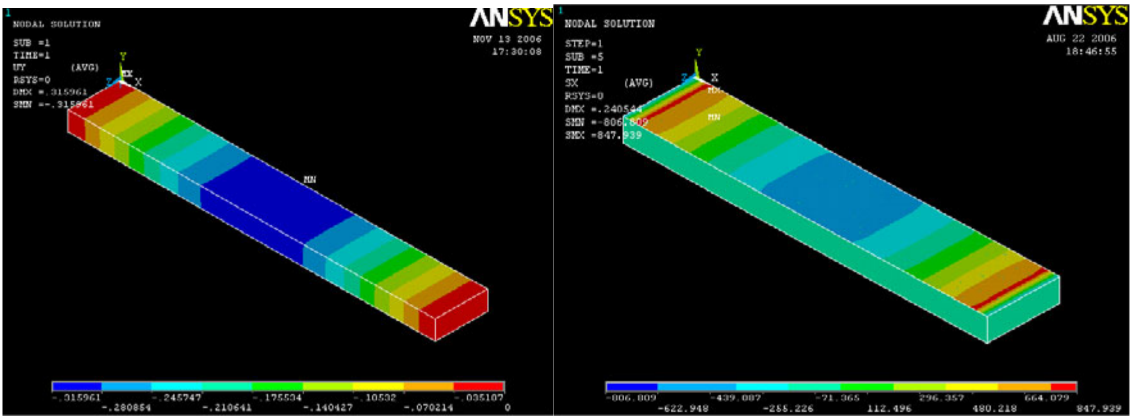
It was observed that at the impact energy of 2600 J, the top face of the CSIPs was significantly damaged. The impactor left an indentation on the impacted facesheet of the CSIP. Significant ductility is imparted due to the PP matrix used for impregnating the glass fibers and also due to the low-density EPS foam core. The flexing also helped in deflecting the impactor away from the panel, and there was no penetration through the CSIP panel. Once the impactor hit the top face, the energy was transferred from the impactor to top face. There was, however, no delamination between the facesheet and the core. The foam was seen to have cracked due the applied impact energy. This implies that the strength of the adhesive used for bonding the facesheets and the foam was higher than that of the cohesive strength of the foam cells. The back face was seen to be intact. Hence, the full scale CSIP was able to withstand the applied impact energy of 2600 J, without penetrating the panel, and thus, it can be used as a wall panel in the hurricane prone areas to withstand the wind-borne debris.

Finite Element Analysis

A comprehensive parametric finite element study was done on the proposed CSIP sandwich panels to investigate the effect of important parameters on the deflections and stresses of the panels under out–of-plane loading. The parameters taken into consideration were maximum deflection and the skin stresses. The analyzed panels were large-scale panels with real loading and boundary conditions. Moreover, structural design was done for the proposed panels for floors and walls.

Loads

According to ACI-318 (ACI 2002), and since the deflection is the most important issue governing the design of sandwich panels for roof or floor construction supporting or attached to nonstructural elements not likely to be damaged by large deflections, the allowable deflection is L/240 for total load and L/360 for live load only. In addition to these limits, the slenderness ratio must be taken into consideration in designing the walls.



(a) (b)

Source: M. Mohammed, 2006

Figure 5.10. FEM Results: (a) deflection contours; (b) skin stress contours

ASCE 7-05 (ASCE 2006) was followed in obtaining the dead load and the live loads for modeling the floor and the wall panels. Two methods, ANSYS and American Wood Association (APA) equations, have been used to design the wall panel. The dimensions of the facesheets and the core are obtained by APA equations, and the same are validated using ANSYS modeling. The results obtained by ANSYS showed a deflection of 8.12 mm (0.32"), which is less than the allowable 9.34 mm (0.368"). The final dimensions of the designed panel are shown in Table 5.2.

As seen from Figure 5.10 and Table 5.2, the FEM results and the APA design equations were very close. Difference in deflections existed because the equations did not take into consideration the effect of the properties of TP in the other directions, such as E_y, E_z, and the Poisson's ratios.

Summary and Conclusion

OSB skins in the traditional SIPs were replaced with glass/PP facesheets to produce TP SIPs. These panels were tested under three-point flexural loading. The data obtained from this study can be carefully used for designing structures with TP SIPs. The findings of this study can be summarized as follows:

- TP SIPs can be produced at a much faster rate as compared with the traditional SIPs with the manufacturing technique presented here. At least 24 hours are required for manufacturing the traditional SIP; however, TP SIPs can be manufactured within 1 hour and with less labor-intensive operations.

- Weight savings of 183 percent can be achieved by replacing the OSB skins in the traditional SIPs with TP skins, thus, reducing the total dead weight of the various structural panels.

Table 5.2. Final Dimensions Based on F.E. Design

Span (mm)	Transverse Load (N/mm2)	Axial load (N/mm)	Skin Thickness (mm)	Core Thickness (mm)	Deflection F.E. (mm)	Deflection APA (mm)	Difference (%)
4267.2 (14”)	0.0019 (40 psf)	0.0043 (900 plf)	5.08 (0.2”)	228.6 (9”)	8.12 (0.32”)	9.34 (0.368”)	13

- The ultimate load carrying capacity of the TP SIPs with 1.60 x 10^7 Mg/m^3 (1pcf) core density was 30 N while that of SIPs with 4.80 x 10^7 Mg/m^3 (3pcf) core density was 80 N. This increase in the load carrying capacity can be attributed to the 385.7 percent greater core shear strength of the 4.80 x 10^7 Mg/m^3 (3pcf) core.

- The primary mode of failure under three point bending for TP CSIPs was the shear failure of the foamed core, which resulted in developing shear cracks at an average angle of 45^0 to the horizontal in the foam core. The facesheets were seen to be intact in the case of TP SIPs.

- The primary mode of failure of the traditional SIPs was, however, the rupture of the OSB facesheet on the tensile as well as compressive side of the panel. Along with this the foam was also seen to have undergone shearing and resulted in development of shear cracks.

- For HVI loading, fiber breakage on the impacted face was the predominant mode of failure for CSIPs. There was no penetration through the CSIP panel, but the impactor was deflected away from the panel due to flexing.

- In all the tests, the bond between the facesheets and the foam was intact, and there was no delamination between the facesheet and the foam, proving excellent adhesion between the facesheets and the foam for OSB SIPs as well as CSIPs.

- By replacing the OSB facesheets of the traditional SIPs with equivalent stiffness TP facesheets, lightweight panels can be obtained that have better penetration resistance and better energy absorption under HVI scenarios than traditional SIPs.

- Finite element results were found to be in close comparison with the analytical model; hence, the FEM model can be used carefully for designing the wall and the floor panels using CSIPs in future.

Acknowledgements

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A New Mitigation Strategy—
The Tennessee Multihazard Mitigation Consortium (TMMC)

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Background

A proposal was submitted to The University of Tennessee to create the Tennessee Multihazard Mitigation Consortium (TMMC). The proposed concept of the TMMC was formally accepted by the university in the spring of 2006, and a memorandum of understanding was signed by The University of Tennessee, representing east Tennessee; Tennessee Technological University, representing middle Tennessee; and The University of Memphis, representing west Tennessee to form the consortium in the fall of 2006.

Residents of the state of Tennessee suffer millions of dollars in losses each year from damage to their properties caused by natural and technological hazards. Unfortunately, mitigation to reduce losses from natural hazards in the United States continues to consider natural hazards as individual and independent events when in reality numerous mitigation technologies cross the multitude of hazards and engineering disciplines.

The purpose for establishing the Tennessee Multihazard Mitigation Consortium (TMMC) is five fold: (1) to establish a hazards research consortium, to be headquartered in the Institute for a Secure and Sustainable Environment (ISSE) at the University of Tennessee, to conduct multidisciplinary, multihazard mitigation research that involves participants from other colleges and universities; (2) to allow for the study of the causes and effects of natural, technological, and terrorist hazards; (3) to develop multihazard mitigation technologies to reduce losses for Tennesseans from future hazards; (4) to assist building code officials in interpreting the International Building Code and other standards related to such hazards; and (5) to provide assistance to Tennesseans when implementing mitigation technologies in their homes and businesses.

Tennesseans suffer losses in excess of \$20 million on average each year from natural and technological hazards. From 1993 to 1998, these losses amounted to more than \$171 million. Because of unique events, losses in some years have exceeded the average year losses by an order of magnitude. For example, in 1994 Tennesseans suffered losses from natural hazards in excess of \$75 million. In April of 2002, Tennessee experienced its first declared federal disaster of the year when storms and flooding caused more than \$2 million in losses. The May 2003 tornadoes in East Tennessee resulted in more than \$166 million in losses, affecting more than 100,000 Tennesseans. The most silent and potentially damaging hazard to Tennesseans is an earthquake. Both West and East Tennessee contain deep-seated faults that today are the most active seismic regions in the

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United States east of the Rocky Mountains. Computer analysis shows that a moderate earthquake of magnitude 6.0 occurring in East Tennessee during midday at the location of the November 30, 1973, magnitude 4.6 earthquake would result in more than $2 billion in losses and more than 2,000 casualties in Knox County alone. A recurrence today in West Tennessee of one of the 1811 and 1812 New Madrid earthquakes would result in more than $50 billion in losses and more than 6,000 casualties.

The Federal Emergency Management Agency (FEMA) under the Department of Homeland Security (DHS) has been the lead agency in the United States for providing assistance (through the Stafford Act) and guidance to the public on the impact of natural, technological, and terrorist hazards. In the first half of 2000, there were 29 presidential-declared disasters in the United States for which FEMA had paid out more than $500 million. FEMA is also a partner in the congressionally funded National Earthquake Hazards Reduction Program (NEHRP); however, this program addresses only the earthquake hazard. Tennessee's greatest annual losses from hazards are caused by wind and flooding.

FEMA identifies natural and technological hazards as shown in Table 6.1. Of these 15 hazards, all but two—volcanoes and tsunamis—have had some impact on the state of Tennessee.

Table 6.1. FEMA Defined Natural and Technological Hazards

Dam Safety	Earthquakes	Extreme Heat
Fires	Floods	Hazardous Materials
Hurricanes	Landslides	Nuclear
Terrorism	Thunderstorms	Tornadoes
Tsunamis	Volcanoes	Winter Storms

While volcanoes and tsunamis should not be a focus of the TMMC, technological hazards, such as terrorism, blasting, and structural failures, should be included in its focus. Due to the nature of Tennessee with its dams and nuclear power plants and the Department of Energy facilities in Oak Ridge, a TMMC that has a broad focus on reducing the risk and vulnerability of such facilities from natural, technological, and terrorist hazards must be an important aspect of the consortium.

Because of the difficulty in dealing with multiple hazards, in 1997 FEMA supported the Building Seismic Safety Council in forming the Multihazard Mitigation Council (MMC). The purpose of the MMC is to support FEMA by working to reduce the total losses associated with natural and other hazards by fostering and promoting consistent and improved multihazard risk mitigation strategies, guidelines, practices, and related efforts.

As an example of these support activities, during FY 2002 FEMA issued task orders charging the MMC to (1) continue MMC efforts to assist local governments in developing effective mitigation plans and strategies; (2) continue the MMC exploration of the potential for enhancing the role of the code official in hazard mitigation/

preparedness/response/recovery; (3) continue its efforts to develop mechanisms to gather and publicize hazard mitigation success stories; (4) identify, study, and report on issues surrounding analytical assessments of the benefits ("future savings") accruing from hazard mitigation activity in the United States; (5) develop an introductory mitigation course for graduate planning curricula; (6) administer, manage, develop, and deliver the Emergency Management Institute 2002 Multihazard Building Design Summer Institute; and (7) administer the FEMA/MMC Graduate Planning Fellowship Program.

Based on a study of activities funded by FEMA grant programs between 1993 and 2003, the MMC found that every dollar spent on mitigation saved society an average of four dollars, definitely showing that mitigation pays. The same will be true for Tennesseans and the state of Tennessee with support from the TMMC.

The concept of a TMMC between The University of Tennessee, Tennessee Technological University, and The University of Memphis fits well with the MMC model and goes beyond by conducting research to better understand hazards and developing new mitigation technologies. Based on a national trend, the development of a TMMC consisting of the three state universities to serve Tennesseans is extremely timely.

TMMC Goals

Once established, TMMC efforts will go beyond those of the MMC. As discussed above, the purpose for establishing the Tennessee Multihazard Mitigation Consortium is four fold:

- **Establish a hazards research consortium to be headquartered in the Institute for a Secure and Sustainable Environment at the University of Tennessee that is multidisciplinary and involves participants from other colleges and universities.** By having a hazards research consortium, the three universities can begin educating the next generation of professionals who will have experience in all hazards. Currently only the social science programs at the University of Colorado teach the importance of treating natural, technological, and terrorist hazards as one entity and have been doing so for many years.
- **Allow for the study of the causes and effects of natural, technological, and terrorist hazards.** Allowing for the study of the causes and effects of natural, technological, and terrorist hazards will result in staff members of the universities becoming nationally and internationally recognized as experts on multiple hazards and their relationships.
- **Develop mitigation technologies that, when implemented, will reduce losses for Tennesseans from future hazards.** Developing new cost-effective mitigation technologies will allow Tennesseans to reduce their losses, creating resilient communities throughout the state and resulting in a better quality of life for all Tennesseans.
- **Assist building code officials in the interpretation of the International Building Code and other standards related to such hazards.** As technology advances, building codes and standards have become more complex and from a

multihazard perspective can become contradictory. University faculties represent a resource of knowledge that will be helpful to building code officials.

- **Provide assistance to Tennesseans when implementing mitigation technologies in their homes and businesses.** Proactively providing mitigation implementation assistance to Tennesseans will accelerate the application of mitigation technologies by Tennesseans, rapidly reducing losses to their homes and businesses from future hazards.

TMMC Structure

The TMMC will be structured to help Tennessee citizens and businesses by educating students, the public, and professionals on the broad aspects of the impact of natural, technological, and terrorist hazards on Tennesseans, their homes, and their businesses, as well as how to reduce future losses through the use of building codes, mitigation technologies, and land use planning. All three state universities envision that the TMMC will provide a research experience for undergraduate, graduate, and post-doctoral students.

An advisory board representing key individuals and organizations from Tennessee and the nation will be established to guide TMMC activities.

TMMC Opportunities

Once established, the opportunities for the TMMC are limitless. Examples include positioning TMCC to:

- Become a resource that all Tennesseans recognize for accurate information on hazards and the application of mitigation technologies to reduce losses.
- Become nationally recognized as an expert resource on the application and future development of Hazard U.S. (HAZUS) methodologies for loss estimation from earthquake, wind/tornadoes, and floods.
- Become a recognized technical arm for the Tennessee Emergency Management Agency and for the Federal Emergency Management Agency.
- Develop the next generation of visualization tools to display losses from hazards to the public.
- Establish a partnership with the Oak Ridge National Laboratory to expand TMMC activities to a national scale resulting in the only multihazard mitigation consortium within the Department of Energy national laboratories.
- Develop memorandums of understanding with other DOE national laboratories creating collaboration activities enhancing the reduction of losses nationwide, once the partnership with the Oak Ridge National Laboratory is established,
- Establish a partnership with the TMMC and the Center for Earthquake Research and Information (CERI) at the University of Memphis. CERI is an internationally recognized consortium in earthquake hazards research, especially the New Madrid Seismic Zone in West Tennessee. CERI will bring great depth and expertise to the TMMC for the understanding the earthquake hazards throughout the state of Tennessee. As stated by Arch Johnston, Ph.D., director of CERI: A joint

partnership with the TMMC would significantly enhance CERI's ability to educate Tennesseans on seismic risk and their ability to reduce that risk.

- Partner with IPS to enhance sustainability and improve the quality of life in Tennessee. The University of Tennessee's Institute for Public Service (IPS) provides services to Tennesseans to improve the quality of life providing instruction, research, and public service to municipal, state, and county governments, and business and industry. The TMMC housed within ISSE allows for an easy partnership with IPS because the goals of both organizations are the improvement and sustainability of the quality of life in Tennessee. As stated by Mary H. Taylor, Ph.D., assistant vice president of the University of Tennessee, Institute for Public Service, "This partnership will provide additional expertise that IPS can share with our government and industry customers."
- Create a partnership with the IPS has a First Responder Program. As part of TMMC's technological hazards program, TMMC and IPS will create a partnership, which will significantly advance the benefits to Tennesseans.
- Obtain funding support from FEMA and other agencies and industry to develop mitigation technologies and training seminars on a multihazard approach to risk assessment.
- Position Tennessee to become a "model state" on the use and application of multihazard mitigation technologies.

How Communities Implement Successful Mitigation Programs: Insights from the Multihazard Mitigation Council (MMC) Community Study

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Abstract

As part of a congressionally mandated study, the Applied Technology Council (ATC-61) examined nine communities to supplement its national study that found an aggregate benefit-cost ratio of about four for mitigation grants funded by the Federal Emergency Management Agency (FEMA). Corroborating this aggregate finding, the examination of these nine communities also cast light on how communities can have successful hazard mitigation programs. For high-risk and persistent hazards, institutionalization is required. This involves regular funding streams, support and management by high-ranking community officials, buy-in by all community stakeholders, and transfer of authority for programs though multiple generations of champions. Suitable treatment of low or localized hazards is also desirable. In selecting projects to be undertaken, evaluation by planners and engineers provides key quality assurance.

Introduction

Communities have received federal assistance following major disasters since May 1953, when President Eisenhower declared Georgia a presidential disaster following a catastrophic tornado. Federal funds were intended to supplement state and local efforts when recovery costs exceeded state and local capacities. In June 1980 the Office of Manpower and Budget issued a memorandum, "Nonstructural Flood Protection and Flood Disaster Recovery," directing all federal agencies that provide funds for community recovery and reconstruction to incorporate mitigation into their recovery and reconstruction activities. This memo led to the formation of federal interagency teams following all presidential disaster declarations to investigate and then include nonstructural mitigation measures in state recovery and reconstruction plans. Until 1988, however, the federal government did not provide funding to ensure the implementation of suggested mitigation activities. That changed in 1988 with the enactment of the Stafford Disaster Relief and Emergency Assistance Act (Public Law 100-707), an amended

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version of the Disaster Relief Act of 1974 (Public Law 93-288), which earmarked monies to states, communities, and non-profit organizations for mitigation. Section 404 in the Stafford Act originally authorized the allocation of up to 10 percent of Public Assistance grants for cost beneficial hazard mitigation projects. States could award hazard mitigation grants to affected communities that applied for funding and agreed to contribute 50 percent of the total as the required local share.

The Stafford Act was amended in 1993, as a result of the catastrophic Midwest floods, to assist states and to encourage greater use of mitigation projects following disasters. Effective in June 1993, the 10 percent allocation was raised to 15 percent, and the local match was lowered from 50 percent to 25 percent. In 2000 Congress extended and amended the Stafford Act through passage the Disaster Mitigation Act (Public Law 106-390) (referred to as DMA 2000) to include monies for preventive measures to reduce the long-term costs of natural disasters.

As part of DMA 2000, Congress authorized a study to determine the effectiveness of this mitigation-focused extension of the Stafford Act and its implementation. Specifically, the House Appropriations Committee, Subcommittee for the Veterans Administration, Department of Housing and Urban Development, and Independent Agencies of the 106th Congress mandated "an analytical assessment…to support the degree to which mitigation activities will result in future 'savings'" (ATC 2005). The Federal Emergency Management Agency (FEMA) was directed to fund an independent study of mitigation. FEMA asked the Multihazard Mitigation Council (MMC) of the National Institute of Building Sciences (NIBS), which in turn contracted with the Applied Technology Council (ATC), to conduct the study.

As part of this larger study, nine case studies were conducted to examine and understand the hazard mitigation programs in communities that had received FEMA funding. This paper examines how the data collected in these case studies provide information on how natural hazards risk-reduction programs are formed and how they become successful. This paper is organized into five sections:

- A background section that describes the larger study and noteworthy national results;
- A description of the basic design and conduct of the community studies. Included are key definitions, a discussion of the criteria and methods by which the nine communities were studied, a discussion of how data were collected, and how analyses were performed;
- Descriptions of the nine communities studied, their natural hazards risk reduction projects, and the extent to which programs to reduce risks from natural hazards were established;
- An evaluation of the success of community programs and projects. Where the larger study focused on the use of benefit-cost ratios as the measure of success, we examine additional criteria such as whether or not the community used federal funding to achieve planned programs, accelerate existent programs, and/or establish programs for the first time; and
- Conclusions and recommendations.

Design of the National Study

The ATC research group examined mitigation conducted for earthquakes, wind, and flood under three FEMA programs: the post-disaster Hazard Mitigation Grant Program (HMGP) and two pre-disaster programs, Project Impact (PI), and the Flood Mitigation Assistance Program (FMA). The overall study addressed five questions:

- What are the net benefits of hazard mitigation to the nation?
- Do these benefits vary across types of hazards and mitigation activities?
- What are the potential savings to the federal treasury from hazard mitigation?
- What is the magnitude of the ratio of the benefits to costs of hazard mitigation activities funded by FEMA when evaluated within a community context?
- What, if any, additional mitigation activities and benefits were stimulated by the three FEMA program activities?

The first three questions were largely addressed as part of a national study of the benefits and costs of FEMA mitigation grants awarded between June 1993 and 2003. Analyses were quantitative and performed on a sample of FEMA-funded mitigation activities selected from the National Emergency Management Information System (NEMIS) database. The basic unit of analysis was the individual FEMA-funded grant. The last two questions were addressed in studies of eight communities that were selected purposively from the NEMIS database. A pilot study of a ninth community also was undertaken. In this case, the unit of analysis was the individual community, although quantitative benefit-costs of individual community grants were also assessed. This paper examines the ways in which these case studies contribute to our understanding of how communities might undertake successful programs to reduce risks from natural hazards.

Results on an Aggregate or National Basis

On average the study team found that the aggregate benefit-cost ratio of FEMA mitigation was about four. That is, every dollar spent by FEMA on hazard mitigation saves the nation about $4 in future benefits. A federal dollar spent on mitigation grants potentially leads to an average savings to the federal treasury of $3.65 in avoided post-disaster relief and increased federal tax revenues.

The more detailed benefit-cost assessments performed for community studies more or less corroborated the above aggregate result. In each of the communities studied, FEMA grants were a significant part of the community’s mitigation history. No communities studied developed federally supported grants that taken together had benefit-cost ratios below unity. Benefit-cost ratios by grant, though, varied considerably, as did aggregate benefit-cost ratios by community. Likewise, some perils in the community study (for example, earthquake) had projects with higher benefit-cost ratios for the few communities selected than those in the national study, whereas other perils in the community study (such as floods) sometimes had lower benefit-cost ratios than in the national study. Nonetheless, the community studies corroborated the overall procedures and findings from the national assessment.

Moreover, the community studies often detected additional or synergistic activities. As defined in the next section, these activities can show how FEMA mitigation grants can support, accelerate, or initiate additional risk-reduction activities. These synergistic effects were not identified through quantitative analyses and were only detectable through the conduct of community studies.

Method: Design of Community Studies

After a pilot community study, eight additional communities were selected for in-depth analysis within a multi-case study methodology. The methodology employed three major components: (1) data collection and processing, (2) computation of benefit-cost ratios and the determination of cost-effectiveness for activities with qualitative characteristics, and (3) the identification of synergistic mitigation activities. Data were collected from documents, structured telephone interviews, open-ended on-site field interviews, and archival research. Efforts were made to establish a chain of evidence through triangulation (comparison of multiple, independent sources of evidence), and ordering information chronologically for time series analysis.

Definitions. Considerable time was spent in clarifying definitions. Below are distinctions made between *project* and *process* activities. In addition, three types of synergistic activities or effects are defined: spin-off activities, collateral activities, and spillover effects. As in these community studies, we expect that future community studies might elaborate on how these distinctions clarify community processes in reducing natural hazards risks.

FEMA awarded grants for both *project* and *process* mitigation. *Project activities* involved physical measures to avoid or reduce damage resulting from disasters. These included elevations, relocations, and reinforcement of buildings, lifelines, or other structures to resist or avoid floods, earthquakes, and wind. *Process activities*, in contrast, led to policies, practices, and projects that reduce risk. These included assessing hazards, vulnerability, and risk; conducting planning to identify projects, policies, and practices, and to set priorities; educating decision-makers or others; and facilitating the selection, design, funding, and construction of projects (MMC 2002). Between 1993 and 2003, 90 percent of the FEMA grants in the NEMIS population and 95 percent of costs were for project activities.

Synergistic activities (see Figure 7.1) are the family of activities that reduce risks or increase benefits of risk-reduction activities from floods, earthquakes, and severe winds. The importance of these activities derives from the additional benefits of grants that arise directly or indirectly from their presence. They follow or accompany the award of FEMA mitigation grants or the strong expectation that a grant will be awarded. Synergistic activities are not funded by FEMA and can take the form of spin-off activities, collateral activities, or spillover effects. *Spin-off activities* result from or are enabled by FEMA hazard mitigation grant support directly (an action that would not otherwise have taken place) or indirectly (accelerated timing of an action that would have taken place eventually). *Collateral risk-reduction activities* differ from spin-off activities because FEMA hazard mitigation support had no significant impact on their content or timing. *Spillover effects* include direct and indirect increases in economic activity or value of assets in the more conventional use of the terms *direct* (that is, increase in business activity of new or revitalized enterprises or increase in property value) and *associated indirect* (that is, ripple effects).

Type of Community Program		**INSIGNIFICANT**	**SIGNIFICANT**
	MITIGATION	Collateral Risk-Reduction Activity	Spin-off Activity
	OTHER	Not Applicable	Spillover Effect

Effect of FEMA Grant on Timing of Programmatic Activity

Figure 7.1. Community Activities Following FEMA Grants

Two questions were asked to determine whether an activity was a spin-off. The first question asked was whether there was a high chance that the activity was financed or supported because FEMA provided support or was expected to provide support for another process or project activity. If the preponderance of evidence from telephone interviews, face-to-face interviews, and documents indicated that the answer was “yes,” then the activity was considered a spin-off. If the answer to the first question was “no,” then a second question was asked: Did the FEMA grant accelerate the activity in question? If the answer to the second question was “yes,” then the activity was a spin-off activity. If the answer was again “no,” then the activity could not be a spin-off activity; it, however, could still be a collateral activity.

Spillover effects were determined from more detailed field evaluations of how various types of commercial or industrial activities may have been accelerated or initiated as a result of mitigation grants. For instance, a downtown revitalization project may have been made possible as a result of a grant to reduce natural hazards risks to the downtown area.

Pilot Study. The pilot study community was purposively selected using eight criteria to identify communities that would have received significant FEMA mitigation funds and that had established a robust community mitigation program. To be eligible, potential pilot communities must:

1. Have received at least $1 million from FEMA in mitigation funds from HMGP grants, FMA grants, and Project Impact (roughly 8 percent of the communities in the NEMIS database had received this amount of funding);
2. Be a geographically free-standing city, not adjoining or encompassed by a larger community that had received significant FEMA mitigation funds, or part of a county with many incorporated cities or a large population living in unincorporated areas (to be able to focus on one community and avoid cross contamination);
3. Have a population between 50,000 and 500,000 (a principal city in an SMA must have a population of at least 50,000, and cities exceeding 500,000 are considered megacities);
4. Be riverine flood-prone (by far the most significant hazard in the United States is riverine flooding, and there are more mitigation grants for floods than any other hazard);
5. Have a ranking of 6 or better (1 being best on a scale of 1 to 9) in the Community Rating System (CRS) of the National Flood Insurance Program (NFIP); (the CRS is a voluntary program in which communities agree to adopt and enforce flood regulations in excess of NFIP minimums; the more comprehensive the flood mitigation regulations, the better the CRS rating);
6. Have excellent records relating to its natural hazards mitigation efforts;
7. Have accessible records relating to its natural hazards mitigation efforts; and
8. Have at least one additional exposure either to wind or earthquake hazards.

Only eight communities met criteria 1, 3, and 5, and Tulsa, OK, was the only community to meet all eight criteria.

Eight Communities. Purposive sampling techniques also were used to select eight communities from the NEMIS data set for in-depth study. To be eligible for study, communities must:

1. Have received awards from FEMA where the objective was to mitigate damage from earthquakes, flood, or wind (coastal storm, hurricane, severe storm, tornado, typhoon);
2. Be at high risk of earthquakes, floods, or wind hazard(s);
3. Be a single jurisdiction identified with a legal title as a city, town, borough, village, or county within one of the 50 states;
4. Have received grants for both project and process (includes Project Impact) mitigation activities;
5. Have received awards that summed to $500,000 or more; and
6. Have received no more than 15 grants.

One hundred thirteen communities met criteria 1 and 3 through 6, but only 76 communities were at high risk of at least one hazard.

Communities were sorted and quota limits were set to maximize the probability that the communities selected for study varied in (1) the combination of grants they had received from FEMA (earthquake only, wind only, flood only, earthquake and flood, wind and flood, earthquake, wind, and flood); (2) whether they were at high risk of earthquake, flood, and/or wind; (3) community population (small, 10,000-49,999; medium, 50,000-499,999; large, 500,000 and greater); and (4) FEMA region. Quotas were set for each criterion to ensure that the communities selected represented the population from which they were drawn but did not over-represent any one type of community. For example, 40.7 percent of the communities that had received awards had populations between 10,000 and 49,999 persons, while 49.6 percent had populations between 50,000 and 499,999, and 9.7 percent were 500,000 or more. Quotas were set such that, of the eight communities studied, no more than four were small communities, no more than four were medium-sized communities, and no more than two were large communities.

communities were written on pieces of paper. The 76 pieces of paper were placed in a basket, shaken up, and the first community was drawn. The process was repeated until all communities were drawn. The eight communities selected for analysis are shown in Table 7.1.

Table 7.1. Communities Selected for the Sample by Community Size, Pattern of FEMA Awards Received and FEMA Region.[a]

Pattern of FEMA Awards (Quota Set)	Small Communities (10,000-49,999) (Quota Set: #4)	Medium Communities (50,000-499,999) (Quota Set: #4)	Large Communities (≥500,000) (Quota Set: #2)
Earthquake Only (#2)		Hayward, CA (Region IX) Orange, CA (Region IX)	
Flood Only (#4)	Jamestown, ND (Region VIII)		Multnomah County, OR (Region X)
Wind Only (#2)			
Flood and Earthquake (#1)			
Flood and Wind (#4)	Freeport, NY (Region II)	Tuscola County, MI (Region V)	Jefferson County, AL (Region IV)
Flood, Earthquake, Wind (#1)		Horry County, SC (Region IV)	

[a] Quotas for FEMA Regions were: Region I (#1); Region II (#1); Region III (#2); Region IV (#4); Region V (#2); Region VI (#2); Region VII (#1); Region VIII (#1); Region IX (#3); Region X (#2).

The selection of communities based on random draws guided by quotas ensured that the relatively small number of communities selected for study would represent a full range of conditions, without allowing the researchers to personally "choose" any particular community (that is, "cherry pick").

Data Collection. Data were collected in four phases: pre-interview activities, formal telephone interviews, field visits, and data or information processing. Pre-interview activities included the collection of documents, reports, and other data from FEMA regional offices, state offices of emergency management, libraries, and the Internet that could be used both in benefit-cost analysis and in identifying knowledgeable persons to interview in each community. Persons identified in each community were interviewed by telephone using a standardized interview guide. Respondents were asked about existing hazard mitigation regulations or laws, their knowledge of current natural hazard risks, their knowledge of community hazard mitigation activities, their knowledge of specific FEMA-sponsored mitigation activities and their effectiveness, their knowledge of any partnerships that were key in affecting mitigation for the community, and referral information for other knowledgeable persons in the community. Persons selected for interview were identified both from collected documents and through a process of network sampling. FEMA personnel introduced the research team to one key person in each community. The first telephone interview was conducted with that person who was then asked to provide names of others who were knowledgeable about hazard mitigation in the community. This process continued until no new names were recommended.

Field investigations took place after telephone interviews had been completed and the mitigation grant and Project Impact files had been reviewed. Field investigations had two goals: (1) to find information independent of information contained in the federal and regional files or gathered in telephone interviews, and (2) to identify additional mitigation activities conducted by the communities and additional knowledgeable persons to interview by telephone. The focus of these on-site efforts was on obtaining objective documentation in the form of written documents, compact discs, videos, and other records, rather than on discovering opinions and perceptions.

Analysis. Information from all sources was combined to provide (1) a description of each community, its risk of natural disasters, historical decisions concerning hazard mitigation, and hazard mitigation activities that preceded and followed FEMA grants; (2) a list and discussion of FEMA hazard mitigation grants; (3) a discussion of the project impact if the community had received a Project Impact grant; and (4) an activity chronology to illustrate the temporal relationship of hazard mitigation decisions and activities included in steps 1 through 3. The activity chronology diagram is constructed in two dimensions. The vertical axis (y-axis) is comprised of those factors or elements that generally are associated with hazard mitigation programs. They consist of community participation plans, capacity building, ordinances and regulations, other state and federal grants and programs, FEMA grants and programs, and state laws. The horizontal axis (x-axis) illustrates the chronological relationship between the start of grants for project or process mitigation activities funded by FEMA and the start of other community mitigation activities. This visualization provides a simple means of determining if there is a potential causal relationship between FEMA grants and synergistic community activities.

A benefit-cost analysis was performed on all FEMA-funded activities identified in the community studies analysis. In general, the community studies benefited from the vast amounts of background engineering and science, not available in NEMIS, which assisted in the development of benefit-cost evaluations. Not only did FEMA regional offices and local communities provide considerable help in gathering such background information, they also assisted greatly by providing materials for additional analyses, such as the identification of spin-offs and spill-over effects. The detail often available in the community studies also created disadvantages by, for example, identifying perils (for exmple, storm overflows affecting storm drains, debris flows) and structures (for example, sodium hypochlorite wastewater facility, booster pumps) funded by mitigation grants that were outside the scope of the national study.

Community Descriptions. Descriptions of the selected communities, including the pilot study community, follow.

Tulsa, Oklahoma. Tulsa is located in Tornado Alley, which makes it susceptible to thunderstorms, tornadoes, and floods, generally the result of localized downpours of up to 15 inches in six hours. Historically, the city has flooded often. In the 15 years between 1971, when it joined the National Flood Insurance Program (NFIP) and 1986, Tulsa had floods that resulted in nine presidential disaster declarations, making the city the most flood prone community in the country. Outcries from citizens after each successive flood prompted the city to develop and implement a comprehensive floodplain and stormwater management program that eventually became the model for other cities.

The flood program has a number of important characteristics. In 1974, Tulsa became one of the first communities to purchase severely damaged houses after a flood. It unsuccessfully asked FEMA to pay for part of the cost using Section 1362 of the National Flood Insurance Act funds; however, after a catastrophic 1984 flood, FEMA approved Tulsa's continuing request for 1362 funding, the first time FEMA agreed to financially contribute to acquisitions. When Tulsa first acquired houses as part of its floodplain and stormwater management program, it established permanent earmarked funding sources to pay for small projects, large projects, and maintenance. A stormwater management fee was added to monthly utility bills; a "fee in lieu of detention" was paid by developers to offset downstream impacts of construction; and voters approved bond issues and the use of sales tax revenues to finance various capital elements of the program. The city worked with the Army Corps of Engineers to plan and build structural flood control works to complement non-structural programs like acquisition and adopting stricter ordinances for floodplain management than the minimum required for communities in the NFIP.

Since FEMA established the CRS, Tulsa has led the nation in adopting practices that exceed of NFIP minimums, and consistently has been the highest ranked CRS community in the country. Currently, it is the only community with a "2" rating, and it is likely that it will become the first to be granted the highest "1" rating. Among other things, it plans and evaluates new developments based on total basin urbanization rather than current conditions and stipulates that development can produce no adverse impacts elsewhere.

The success of the Tulsa floodplain and stormwater management program is reflected in the fact that the city has not had a flood that necessitated a presidential disaster declaration since 1986. There are a number of reasons why Tulsa has been successful. First, there have been three generations of floodplain management advocates within the community and city staff; it is unusual to find a program that has been sustained for this length of time. Second, the program includes input from every stakeholder group and gives citizens a prominent role in the decision-making process. Third, the institutionalized program is operated and maintained by the highest ranking officers of the public works department with the support of elected officials. Fourth, the program utilizes private-sector planning and engineering experts to work with and supplement city staff. Fifth, the construction and development communities have partnered with the city to make the program work. As a measure of success, no structure constructed after the city adopted its floodplain management building ordinances in 1979 has ever been damaged by a flood. And sixth, the city sets reasonable goals each year as part of a long-range program that gradually reduces flood risk in accord with its resources and funding opportunities.

Because of its experience with major tornadoes, FEMA established its first safe room demonstration program in Oklahoma in 1999. With pass-through funding initially provided by FEMA to the state and then to Tulsa, Tulsa aggressively encouraged the purchase of safe rooms by current homeowners and the inclusion of safe rooms in newly constructed houses. Building on its experience with floods, Tulsa worked with contractors in starting an initiative that has resulted in safe rooms being included in many new homes. The city has also assisted healthcare facilities and schools construct safe rooms and started a pilot project for the inclusion of safe rooms in low-income housing. As a result, Tulsa is probably one of the most progressive cities engaged in tornado mitigation.

Tulsa's experience with FEMA hazard mitigation grants has been symbiotic; both parties have benefited from the relationship. The grants have both stimulated and supplemented local activities in Tulsa as well as given FEMA an opportunity to showcase its grants using Tulsa as an early adopter. Unlike the floodplain and stormwater management program, which preceded FEMA involvement, the tornado mitigation program began with the 1999 FEMA safe room grant to the state of Oklahoma. Funds for 100 saferooms were allocated to Tulsa. That grant led to the other spinoff initiatives mentioned above.

Freeport, New York. Originally, a wetlands on the southern shore of Long Island, Freeport was settled as a fishing port, then a weekend retreat for New Yorkers, and finally an urban village for permanent inhabitants. Throughout its history, one thing remained constant: The lowlands of Freeport flooded during lunar high tides, and the city was at risk from storm surge and wind. As a result, some houses flooded more than once a year.

In 1960, residents demanded that the city do something to reduce the constant flooding. The village responded by raising road grade levels and instituting drainage work. Until

1983 the city dealt with flooding sporadically. In 1983, the village began to routinely elevate streets using the revenue from the issuance of general obligation bonds, later from financial grants from the state and federal departments of transportation, and lastly from FEMA hazard mitigation grants. To protect new homes and businesses from floods and wind, Freeport adopted one of the most stringent building codes in the state of New York. It joined the CRS in 1992 and had a rating of 8 in 2001. FEMA's contribution to the city's mitigation plan was a significant infusion of funds that paid for several years' worth of planned street elevations.

While the city appropriated funds to raise streets above the 100-year flood level required by the NFIP, it also received several hazard mitigation grants from FEMA to elevate private structures (assuming the owners paid the local share). By 2003, a significant percentage of the streets and a number of structures in Freeport had been raised, thereby reducing the number of structures that flooded regularly. Private development of the main commercial street, Woodcleft Avenue (also called the Nautical Mile), was an economic consequence or spillover of the city's ability (with FEMA assistance) to reduce flooding. Freeport's involvement with Project Impact strengthened the community's participation in mitigation while also promoting a city flood damage reduction program to raise bulkheads.

Like Tulsa, Freeport has sustained a robust mitigation program for more than 20 years. There are a number of reasons why Freeport has been successful. First, there have been two generations of floodplain management advocates within both the community and the city staff. Second, the village has been proactive in seeking funding for mitigation; it is one of the few communities with a dedicated grant manager. Third, the program is supported by citizens and the business community, both of which have seen their property values increase as a result. Fourth, the institutionalized program is operated and maintained by the highest ranking officers of the public works department and building inspection with the support of elected officials. Fifth, the village tries to accomplish reasonable goals each year by establishing a long-range program that gradually reduces flood risk in accord with its resources and funding opportunities.

Hayward, California. Hayward is a moderate sized city south of Oakland on the east shore of the San Francisco Bay. Its downtown business district straddles the Hayward earthquake fault. The city began to understand its earthquake risk in 1986 after it formed the Hazardous Building Mitigation Task Force (HBMTF) to identify all the unreinforced masonry buildings (URMs) within its boundaries in accordance with the state of California's URM Building Law. As part of its charter, the city asked the HBMTF to create an inventory of all URMs built before 1944, as well as all tilt-up buildings constructed prior to the 1973 building code adoption and all high-occupancy (300 or more persons) reinforced concrete buildings built prior to 1976.

Just before the HBMTF completed its task in late 1989, the Loma Prieta earthquake struck northern California and offered an opportunity for Hayward to apply for FEMA hazard mitigation funds. The city ultimately received mitigation grants to relocate its main fire station, retrofit five other fire stations, and replace its wastewater treatment plant. The city of Hayward also asked the HBMTF to recommend mitigation activities it should undertake. The HBMTF recommended that the city require owners of the URMs and tilt-ups to retrofit their structures. In addition, the city council voted to retrofit all vital city facilities and established an emergency services facilities tax to generate the funds needed to repay general obligation bonds issued for that purpose.

Approximately one year after the Loma Prieta earthquake, Hayward established a comprehensive earthquake mitigation program that was highly successful. According to officials, within five years of program implementation, all but three owners had retrofit URMs, all tilt-ups were retrofit, the city constructed a new city hall on base isolators, all the fire stations were seismically improved, a new and less hazardous wastewater treatment plant was constructed, and plans for the improvement of other city facilities were completed, but not yet implemented. Because of the simultaneous occurrence of the Loma Prieta earthquake and the near completion of the HBMTF inventory of seismically dangerous buildings, it was difficult to separate what the proximal causes of the two retrofit ordinances were. Since the city had not previously enacted any seismic ordinances, we ultimately considered them spin-off activities. Unlike Tulsa or Freeport, which had established mitigation programs prior to their first FEMA mitigation grants, Hayward was just learning what its seismic risk was when the Loma Prieta earthquake made it possible for the city to apply for mitigation grants.

There are several reasons why Hayward was able to turn this opportunity into a successful mitigation program. First, Hayward found out that the city had a manageable problem that could be addressed by the city and cooperative owners of private URMs and tilt-ups. When it enacted retrofit ordinances for the URMs and tilt-ups, there was no opposition. Remarkably, Hayward was then and still is the only community in the United States to mandate that private owners retrofit tilt-up buildings. Second, the city officials were proponents of mitigation, a common characteristic of communities in earthquake country.

All of the communities in our study had some flood risk. Hayward had suffered very little flood damage in its history and considered its risk from flood as low. It joined the NFIP in 1981 and has enacted ordinances to implement building codes that meet the NFIP minimum requirements. From a managerial point of view, the city response to floods has been sound and appropriate to the risk.

Horry County, South Carolina. Horry County is located on the Atlantic Coast about 100 miles north of Charleston. It is relatively flat and filled with wetlands, rivers, and beachfront. Its major cities, including Myrtle Beach, attract about 13 million visitors a year, mostly during the summer months at the height of the hurricane season. Because of its geography and location, Horry County is at high risk from floods and hurricanes and moderate risk from earthquakes.

Horry County is one of the fastest growing regions of the country. Once noted for pine forests that traditionally were harvested for paper products, the county is now undergoing drastic changes as the paper corporations clear the trees and develop numerous subdivisions. One contractor estimated that the county will gain 50,000 new homes and complementary businesses and golf courses in the next 20 years.

Horry County was late in joining the NFIP, which it entered in 1984 at about the beginning of the current growth movement. The potential increase in flood risk caused by the removal of the forests was addressed in 1987 when the county enacted its flood damage and control ordinance and hired its first flood hazard reduction officer in 1988. This was supplemented by the passage of the Stormwater Management Utility Ordinance and fee in 2000. Unlike other communities such as Tulsa and Freeport, flood control and stormwater management were placed in separate county departments. Traditional riverine flood control was placed in Emergency Management, and flood control and stormwater management emanating from new development was placed in the engineering department, where evaluations of new construction are made. The two sources of flooding were considered different and unrelated, with the consequence that the two programs are run independently.

Horry County received multiple FEMA mitigation grants and was selected as a Project Impact community in 2001, the last year of the program. The emergency manager managed all the grants. The vast majority were for buyouts following Hurricane Floyd in September 1999. One characteristic not seen elsewhere was that those who volunteered to be bought out generally did not possess waterfront property, which was rising in value as the population was expanding. Instead of being rehabilitated by their owners, many severely damaged waterfront properties were being sold at prices in excess of buyout offers to wealthy new owners, who tore down the existing structures and replaced them with much larger and expensive houses that met NFIP building standards. When houses were purchased, the county creatively contracted with neighbors to maintain the resulting open spaces and to utilize the properties as expanded back yards if they so chose.

There was one spin off in Horry County. After the purchase of 13 houses, the county collaborated with a Clemson University civil engineering professor in systematically destroying the structures and testing their ability to withstand forces equivalent to strong winds. The project had as its objective the development of proposals to change national model building codes and standards to improve the wind resistance of private houses (Rheinhold 2002).

Horry County had mixed success with its mitigation program. On the positive side, the vast majority of the mitigation projects undertaken in the county were completed successfully. Highlights included the purchase of many houses, several with repetitive NFIP losses, and the wind resistance study with Clemson University. On the negative side, the emergency manager worked basically alone, without much interaction with or support from other county officials. The entire county mitigation effort was ultimately dependent on the skills of a single person. While relatively successful in completing most projects, the emergency manager was unable to complete other projects, especially those funded through Project Impact. Finally, by the end of this study, the emergency manager had left the job and had not been replaced, throwing into question the county's ability to build on any prior successes. By way of contrast, Tulsa and Freeport both had well trained successors in place when their mitigation bosses left.

Jamestown, North Dakota. Jamestown is a small rural city located in east central North Dakota at the confluence of the James and Pipestem Rivers. It had a history of flooding, mostly caused by spring runoff from melting snow in upstream mountains. However, because of recent high water tables, heavy local rains have overwhelmed the sanitary and stormwater sewer systems and caused basement flooding. Jamestown was included in 11 presidential disaster declarations related to flooding between 1966 and 1999.

Spring floods were common until 1973. At that time the U.S. Army Corps of Engineers had completed the Pipestem Dam and lake to control river flows and began regulating both the Pipestem and James rivers. Previously the Bureau of Reclamation had constructed the Jamestown Dam and reservoir on the James River in 1954. According to Project Impact documents written in 2000, the city of Jamestown did not consider overbank flooding a potential natural hazard threat.

Jamestown received two hazard mitigation grants in the mid-1990s and a Project Impact grant in 1999. Overall, the mitigation projects addressed relatively minor problems, consistent with the city's assessment of the risk that natural hazards posed. The most significant project was the completion of a stormwater runoff study conducted by a local engineering firm and later used in the design of a new high school.

Jamestown, like Hayward, has been successful in managing mitigation programs because they are relatively small and manageable. Like Tulsa, Freeport, and Hayward, Jamestown has had support from throughout the city government, and like Tulsa, from outside experts who have worked with the city for many years, thereby supplementing limited city technical capacity. Two generations of public works officials have been prominent in the support of hazard mitigation, reflecting that mitigation has been institutionalized in the city.

Project Impact permitted Jamestown to increase its preparedness for tornadoes, a moderate threat to the community. The city was able to implement warning systems to receive a "Storm Ready" designation from the National Weather Service.

Jefferson County, Alabama. Jefferson County is located in north central Alabama on the southern extension of the Appalachian mountain range. It is the most populated county in the state with 35 political jurisdictions (incorporated cities and towns) including Birmingham, the largest city in the state. Because of its location in the foothills of the Appalachians, Jefferson County is susceptible to flash flooding and severe tornadoes.
However, until an F5 tornado devastated the county on April 8, 1998, the county government had not been very active in hazard mitigation.[5]

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[5] Flooding on Village Creek had devastated the city of Birmingham for years. Long before Jefferson County began its mitigation efforts, Birmingham had already been involved with the U. S. Army Corps of Engineers in one of the largest buyouts of private homes in the country.

In the years following the tornado, the Jefferson County Emergency Management Agency, under the leadership of the county commissioner with administrative responsibility for emergency management, established a comprehensive mitigation program aimed at reducing damage from floods and tornadoes. Initially, in responding to the tornado, Jefferson County received numerous grants from the U.S. Department of Housing and Urban Development to assist in recovery and provide low-income residents with new or improved housing. FEMA also provided the state of Alabama a grant to partially fund the construction of safe rooms, similar to the grant previously awarded to Oklahoma. Like Tulsa, Jefferson County received pass-through funds from the state to partially pay for the construction of 100 safe rooms for which homeowners could apply.

Then in 1999 Jefferson County was awarded a Project Impact grant that permitted the county to develop its first comprehensive local mitigation strategy, upgrade its emergency operations center, and upgrade its early warning system (sirens) that could be used for both flash floods and tornadoes. A few months after being awarded the Project Impact grant, the county was subject to severe flooding along Upper Shades Crest Creek, the first of what county officials believed were three 100-year floods in four years. Between 1999 and 2001, the county was awarded nine FEMA mitigation grants in the aftermath of these floods, including two to produce hazard mitigation plans and six to acquire structures severely damaged in the floods.

Not content to rely upon uncertain future funding opportunities that take place following presidentially declared disasters, the county moved forward on two spin-off initiatives. First, the county council adopted an ordinance in 2003 that allocates $2 million annually for the purchase and removal of private houses throughout the county subject to severe flooding. Second, through its Community Development Agency, the county undertook the development of a subdivision of 80 residences in the area devastated by the 1998 F5 tornado for low-income families with each containing a safe room.

Jefferson County has had a progressive mitigation program for only seven years, and it is too early to conclude that it will become as robust as those in Tulsa and Freeport. However, there are many positive signs indicating success will be a likely outcome. The initial impetus for the Jefferson County mitigation efforts was based on the efforts of the single county commissioner, who used her position to promote, support, and provide funding for county projects, and a talented and experienced emergency manager who was able to convert ideas into practical programs. The county commissioner is still leading the charge and, following the retirement of the emergency manager, a second-generation emergency manager has taken up the cause. Other talented county employees have also become proponents of mitigation and provided both leadership and the necessary skills to develop and accomplish the mitigation projects Jefferson County has undertaken. Like Tulsa and Freeport, Jefferson County has also approached its flooding and tornado problems as long-term efforts that attempt to resolve the most needy problems first. The enacted ordinances imply that the county has institutionalized mitigation and will devote considerable resources to mitigation annually and not rely on quixotic outside sources.

Multnomah County, Oregon. Multnomah County is located in northwest Oregon along the Columbia River. Within Multnomah County are the cities of Portland and Gresham, where 94 percent of the county's population reside. Multnomah County has jurisdiction over less than 35,000 people, who are spread out in unincorporated suburban and rural areas.

Within Multnomah County, both Portland and Gresham have established strong mitigation programs that Multnomah County has chosen not to emulate. It has joined the NFIP and meets the minimum requirements. It received two mitigation grants from FEMA and was selected by the state of Oregon as a Project Impact community after it agreed to apply with two sub-county organizations after their initial application without the county as a partner was turned down by the state. The two mitigation grants were awarded to acquire private houses that were destroyed, partially damaged, or threatened by a landslide in 1997. The county formulated neither the grants nor Project Impact as part of an on-going mitigation program.

The Multnomah County Project Impact program was the only one evaluated that failed to achieve most of its project goals. A political reorganization caused by a change in county administration and a budget shortfall led to a cutback or cancellation of the projects. Multnomah County was also the only community that had never initiated any synergistic activities.

City of Orange, California. The city of Orange is located just south of Anaheim in Orange County, California. It was originally constructed around a central plaza called "Olde Towne," which is still the heart of the community. Although the city is located along the Santa Ana River and is in earthquake country, it has never suffered any major flood or earthquake damage.

The community joined the NFIP in 1987 and adopted the minimum required codes. A local flood mitigation program was never initiated because flood mitigation has been provided by the U.S. Army Corps of Engineers, which controls the Santa Ana River's flow with the Prado Dam, built upstream of the city. According to public works officials, recent improvements to the Corps' flood prevention structures have taken all of the existing buildings out of the 100-year floodplain, and the risk from flood is now considered to be low.

The city of Orange got involved with earthquake mitigation at the same time as Hayward, following the mandate of the state URM Building Law of 1986 to inventory their unreinforced masonry buildings. The city completed its inventory in early 1990 and identified approximately 60 such buildings in the city limits, most in Olde Towne. Going beyond the state requirements, the city passed an ordinance in 1992 establishing minimum standards for structural seismic retrofit and then passed a second ordinance to provide funds to assist owners who voluntarily retrofit their buildings. By the sunset date of December 1998, 51 or 85 percent of the eligible buildings were retrofit.

Following the Loma Prieta earthquake, the city of Orange was awarded five mitigation grants in 1998 to retrofit several public buildings, including city hall, fire department headquarters, a city yard warehouse, a city yard garage, and a water plant. The latter three projects were completed; but the first two were not because actual costs far exceeded the award amounts and the city was not willing to pay the additional costs after FEMA refused to increase the awards.

Since the cancellation of the two projects, the city has decided that it would be more prudent to construct a new city hall instead of retrofitting the old one. The city began to set aside funds for the retrofit of the fire department headquarters and the new city hall, but recently the funds were diverted for the construction of a new city library.

The city of Orange's success in mitigating its natural hazard risks is similar to Hayward's. Like Hayward, the city of Orange was confronted with manageable flood and earthquake problems that could be simply addressed by the city and cooperative owners of private URMs. When it enacted retrofit ordinances for the URMs and agreed to fund approximately half of the cost, there was no opposition. Also like Hayward, the city officials were proponents of mitigation, a common characteristic of communities in earthquake country.

Tuscola County, Michigan. Tuscola County is a rural county in east central Michigan just north of Flint and just east of Saginaw, located along the shore of Lake Huron. Approximately ten percent of the county is covered by water. Because of its geographical location, it is subject to both floods and tornadoes. According to the state constitution, the relationship between municipalities and counties is different from most other states; all property must be included in incorporated municipal jurisdictions that are responsible for land use decisions, but counties have been granted certain powers including being responsible for all drainage activities including flood mitigation. A successful flood mitigation program requires the cooperation of the elected county drainage commissioner and municipal leaders.

Within Tuscola County, flooding has been common, especially in the Village of Vassar along the Moore Drain and Cass River, whose confluence is near the center of town. The flood mitigation program that has developed in Tuscola County is located in Vassar. The first FEMA mitigation grant was awarded to Vassar in 1986 under the authority of Section 1362 of the National Flood Insurance Act. Using the same authority that was pioneered in Tulsa a few years earlier, FEMA provided funds to acquire several substantially damaged houses following a major flood.

In 1996, another major flood caused severe damage to residences, the historic business district, and the delivery of emergency services within the community. Using powers specified in the state Drain Code of 1956, the Tuscola County drain commissioner worked with local Vassar officials and concerned citizens to apply for FEMA mitigation grants. Four grants were awarded to the Tuscola County Drainage Commission between 1998 and 2004, two of which involved structural improvement to the Moore Drain. The potential reduction in flooding prompted citizens to redevelop the downtown, a spillover effect.

The reasons for Tuscola County's successful flood mitigation efforts are unique among the communities in this study. A village-county partnership with shared goals of both reducing flooding and improving the living conditions of citizens partially explains their successes. Like other communities, the program has been operated and maintained by highly placed elected officials, such as the drainage commissioner. Like Jefferson County, it is too early to tell if the flood mitigation program will survive after the current elected officials leave office.

Evaluation of the Success of Community Programs and Projects

Reasons for Success. When most people think about successful hazard mitigation programs, they think of communities that have developed reputations for successfully addressing their highest risk natural hazards. An analogy is David overcoming Goliath. The community studies pointed out that this belief is partially true. Successful communities are those that have implemented programs addressing high-risk hazards but also have appropriately managed their lower risk natural hazards. In addition, their programs have been managerially and fiscally sound. Long-term coordinated policies and projects have been implemented to reduce risk for substantial high-risk hazards, and short-term policies and projects have been implemented to contain and/or reduce risk from hazards affecting a small percentage of the community, which could be low, medium, or high-risk hazards. Overall, these communities have institutionalized their programs, established funding mechanisms, and allocated their agency resources to match the scope and severity of each natural hazard the community faces. In many cases, the communities have engaged local planning and engineering experts to supplement agency resources and/or provide expertise beyond local abilities. In seven of the communities (Tulsa, Hayward, Horry County, Jamestown, Jefferson County, the city of Orange, and Tuscola County), the outside planners and engineers were engaged to select and qualify projects worth undertaking and/or complete the projects.

Every community in the study faced a flood risk. Their approaches to flood mitigation varied. It is instructive to review their programs and identify the factors associated with success and failure. Four communities (Tulsa, Freeport, Horry County, and Jefferson County) shared a high risk from flood that affected a large portion of their population. Three communities (Tulsa, Freeport, and Jefferson County) each established long-term programs to reduce risk. In Tulsa and Jefferson County, one main element was the systematic purchase of houses in the floodplain. In Freeport, a related program was the systematic elevation of streets and houses. The other community with a similar high flood risk, Horry County, had not established a long-term program to deal with riverine floods. After completing its acquisition grants, Horry County did not establish a program that considered the remaining risk. All four communities, however, had established flood control and stormwater management programs to ensure that new construction would meet NFIP standards. Tulsa, Freeport, and Jefferson County institutionalized their efforts by joining the CRS, and Tulsa and Horry County established stormwater management fees to sustain their programs.

The remaining five communities (Hayward, Jamestown, Multnomah County, the city of Orange, and Tuscola County) either were at low risk of floods or were at high risk of flood in only an isolated segment of their communities. These were dealt with as manageable problems that could be addressed by a single solution. In two of the communities, Jamestown and the city of Orange, the U.S. Army Corps of Engineers has provided structural protections leaving the cities with little residual risk. They, along with Hayward, found that implementing the minimum flood management ordinances required by the NFIP provided a satisfactory approach to managing their floodplains. Multnomah County and Tuscola County both used FEMA mitigation grants to address specific flood prone areas. Tuscola County invested in structural improvements to local flood control systems, and Multnomah County invested in buyouts to remove citizens from high-risk areas. Based on what happened in these two counties, it is unlikely Multnomah County will expand its mitigation program, and it is probable but not certain that Tuscola County will develop a long-term program or address other problems by improving flood control structures.

What is a successful flood mitigation program? As noted above, it depends on the flood threat and the community response. If there is little threat, an appropriate response is to join the NFIP and implement the minimum requirements of the program. If the threat is manageable, a direct solution is appropriate such as improving a flood control structure to reduce flooding in a specific area. If the threat is high and a relative large segment of the community has a flood risk, then the community should adopt a long-term solution to gradually reduce the risk.

What role do FEMA grants play in the process? If a community has not established a floodplain management program, then a FEMA mitigation grant can help the community either resolve a contained problem or be a catalyst by providing the first effort in a long-term program. If the community has already established a long-term program, then the grants permit the community to accelerate their projects or divert funds to other pressing projects. Among the nine communities, seven (Tulsa, Freeport, Horry County, Jamestown, Jefferson County, Multnomah County, and Tuscola County) had received flood mitigation grants. In Jamestown and Multnomah County, the grants resolved “contained problems.” In Tuscola County, the grants were focused on resolving a contained problem, but may lead to the establishment of a long-term effort. In Jefferson County, the grants led to the establishment of a long-term program. In Horry County, the grants were used to resolve a small part of a large problem, with no indication that the county will establish a long-term program. In Tulsa and Freeport, the grants were used to fund elements of an existing long-term program.

What elements are important for a community to establish a successful mitigation program? Looking at communities without an existing mitigation program and no previous mitigation activities, the old standbys seem important. First, there need to be champions in places of importance who can influence others to establish a program.

Second, there need to be the elements of a program ready to be implemented. Third, there needs to be an opportunity for the champions to implement their program. This is typically called a window of opportunity that generally follows a major disaster. When all three elements are in place, then success is possible but not guaranteed. In this study, Jefferson County and Multnomah County were the only communities that completely fit this pattern but the outcomes to date are very different. Where Jefferson County seems well on its way to developing a sustained multi-hazard mitigation program, Multnomah County is not.

In Jefferson County, the champions were one of the county commissioners and the county emergency manager. The emergency manager was knowledgeable about what the community should do and had worked with the county commissioner to make her knowledgeable. And there was an F5 tornado that killed approximately 30 people and destroyed or damaged more than 1,000 houses followed by a 100-year flood that opened the window of opportunity. As described earlier, once the window opened, the county moved quickly to establish both long-term flood and tornado mitigation programs.

In Multnomah County, the champion was the county emergency manager who was very knowledgeable about hazard mitigation and had begun to train others in the community. A major landslide in the county that was declared a presidential disaster permitted the emergency manager to apply for a FEMA mitigation grant to buyout destroyed, damaged, or threatened houses and proved to be a window of opportunity as well as the acceptance of the county as a Project Impact community. After the window opened, there was a short period in which the county began to establish multiple mitigation efforts and involve private-sector partners. However, after a change in the county administration, the emergency manager was demoted and replaced by a political appointee, who basically shut down the fledgling efforts.

If the champion is not an elected official or the head of an agency or does not have the support of either or both, then short-term success is threatened if the champion is dismissed or leaves. This not only occurred in Multnomah County but also in Horry County, whose program had advanced much further than Multnomah County before the champion left.

Many communities have some history of being involved in mitigation projects that have not led to larger community programs. They too have champions and programs on the shelf ready to be implemented, and are waiting for a new window of opportunity. In this study, the majority of the communities (Hayward, Horry County, Jamestown, the city of Orange, and Tuscola County) fall in this category. Several different outcomes resulted when windows of opportunity opened.

First, Horry County, as described above, suffered the same fate as Multnomah County. The loss of the champion and lack of support from superiors doomed the program. Second, three communities (Hayward, Jamestown, and the city of Orange) were each able to develop and complete projects that basically fully dealt with their risks. Both Hayward and the city of Orange resolved their perceived earthquake risks, and

Jamestown resolved its pressing flood and tornado risks. Unless they designate new hazard-risk problems that they can institute programs to resolve, they will continue to concentrate on managing new developments to prevent any escalation of low risks. Third, Tuscola County in conjunction with the Village of Vassar has just begun to resolve a critical flood problem. The elements are in place for the development of a long-term flood control program, but it is too early to know the outcome.

Two communities, Tulsa and Freeport, have had successful mitigation programs for more than 20 years. It should be remembered that they both have flood problems that require long-term solutions. Their experiences show that long-term success in dealing with long-term problems depends on several things, all of which are measures of robustness. First, when champions leave, they are replaced by a new generation of champions, who have probably been trained by their predecessors. Second, support of elected officials and agency heads remains constant. Third, the programs are institutionalized, engrained in the annual and possibly capital budgets. Fourth, earmarked funding sources are developed to support mitigation so mitigation programs do not compete with other community programs. Fifth, there is a lot of community involvement and support, including the use of local outside consultants to supplement city or county agency staff. Sixth, communities are opportunistic, integrating an expectation of grants from various sources in their planning activities. Seventh, other communities call upon mitigation champions to train their officials and staff. In the process, they learn about new ways to confront hazard risks and integrate new learning into community programs.

Although it may seem so, Tulsa and Freeport are not the only successful communities in this study. Hayward, Jamestown, and the city of Orange are just as successful. The difference is that Tulsa and Freeport have developed long-term programs to deal with long-term hazard risks, while Hayward, Jamestown, and the city of Orange have resolved their hazard risks, which are contained.

Conclusion and Recommendations

Community studies can provide useful information about natural hazard mitigation activities that it is not possible to obtain through other means. This information can be used to confirm findings obtained using other methods and also to identify new and different findings. Additionally, community studies can provide contextual information that can be used to help interpret quantitative findings.

Three important recommendations can be drawn from these study findings. First, to encourage stability and sustainability, mitigation efforts should be institutionalized. Regular funding streams should be identified, and programs should be embedded in powerful departments and managed by high-ranking individuals. Efforts should be made to encourage buy-in at all levels of the local community. Second, it should be recognized that management changes pose a serious threat to mitigation efforts. Champions may be dismissed or leave with little warning; therefore, if not elected officials or heads of agencies, themselves, champions should have the strong support of such individuals to facilitate sustainability. Individual turnover can lead to program vulnerability, and planning transitions well in advance is necessary to facilitate continuity. Third, to maximize efficiency, the intensity of program efforts (and funding) should match the scope and severity of local hazards. The use of planners and engineers to evaluate mitigation alternatives provides a central element in programs that maximize efficiency.

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Achieving Risk Reduction in Critical Infrastructure Systems

Richard G. Little, AICP[1]

Why Manage Infrastructure Risk?

In the United States alone, civil infrastructures represent several trillion dollars of capital investment that society relies on to move goods, people, and information safely and reliably. From an economic, social, and political perspective, it is critical to government, business, and the public that the flow of services provided by these systems continues unimpeded in the face of a broad range of natural and manmade hazards. Understanding and reducing the risks to critical infrastructure is the first step in this process. This paper presents an overview of how risk management principles can be applied in multi-hazard risk reduction strategies.

Defining Terms

Before we can manage risk, however, we need to understand what it is. Risk can be considered as the probabilistic consequences of an adverse event. Although risk is dependent to some degree on the *vulnerability*[2] of that which is acted upon (for example, physical infrastructure) and the *threat*[3] posed by a particular action (likelihood of an earthquake or hurricane), they are not synonymous. This is a key concept in developing cost-effective risk management strategies. Reducing vulnerability in the absence of actual threats wastes resources while not identifying the full range of threats can result in critical gaps in protection.

Assessing and Managing Risk

Risk can be expressed conceptually as the product of the probability of an event and its consequences or $R = P \times C$. *Risk assessment* systematically incorporates consideration of adverse events, vulnerabilities, and event probabilities and consequences. It has classically been defined by three questions (Kaplin and Garrick 1981):

1. *What can go wrong?*
2. *What is the likelihood that it would go wrong?*
3. *What are the consequences of failure?*

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[2] Openness to attack or damage

[3] The intention or potential to inflict injury or damage

What can go wrong?

During different periods in their lifetimes, infrastructure systems must resist a formidable array of threats and insults. In the natural realm, earthquakes, extreme winds, floods, snow and ice, volcanic activity, landslides, tsunamis, and wildfires all pose some degree of risk. To this long and growing list of natural hazards, must be added the tight coupling of interconnected systems, acts of terrorism or sabotage, design faults, excessively prolonged service lives, aging materials, and inadequate maintenance resulting from chronic disinvestment. Neo-liberal business practices can also be viewed as an emerging threat as deregulation and growth of competition in key infrastructures has eroded spare infrastructure capacity that served as a useful shock absorber and mergers among infrastructure providers have led to further pressures to reduce spare capacity as management has sought to wring out excess costs (Marburger 2002). Although analysis of past events, improved prediction and forecasting methods, and engineering approaches to design and construction have improved the ability of infrastructure systems to withstand a wide range of hazards, crippling failures continue to occur (Mileti 1999).

What is the likelihood that it will go wrong?

Ideally in risk calculation, a probability distribution function (PDF) is available, or can be developed, to assign likelihood to hazardous events of various magnitudes. The recurrence intervals of floods, hurricanes, tornadoes, and earthquakes have been determined with varying degrees of precision and reliability, and in the post-9/11 world, attempts have been made to plot the frequency of terrorist attacks, albeit with less faith in their accuracy. The relative infrequency of attacks is compounded by the fact that they are carried out by intelligent and adaptable agents, which makes it difficult to develop such a relationship empirically. However, in the case of terrorism and other hazards where empirical data is lacking or spotty, there are other methods that can be used to develop relative if not cardinal rankings.

For example, probabilities can be elicited from expert opinion (Keeney and von Winterfeldt 1991), simulation modeling (Paté-Cornell and Guikema 2002), or more subjectively from the worldview and risk tolerance of decision-makers (Paté-Cornell 2002). Reagan, Mosteller, and Youtz (1989) assigned numerical ranges to verbal expressions of probability that can be quite helpful in generating relative priorities as a basis for action. If decision-makers can agree that, for their purposes, a highly probable event can be expressed as $p = 0.80$ and an improbable one as $p = 0.001$, an ordinal ranking of risk for a particular hazard can be determined. Such guidance, based on the verbal specification of event probabilities and their estimated consequences, can permit rational action to be taken to mitigate the risk even if the actual probability of an event is unknown (Paté-Cornell 2002).

In path-breaking work, Ellingwood (2001) defined the probability of structural failure over the collectively exhaustive universe of n mutually exclusive hazards, H_i, as $P_f = \Sigma\, P(F|H_i)\, P(H_i)$ where $P(F|H_i)$ is the conditional probability of failure due to hazard H_i, and $P(H_i)$ is the probability of the hazard occurring and

P_f = Total probability of adverse consequences
F = Adverse consequences related to a given hazard
H_i = A hazard of concern

and, for example H_1 = earthquake
H_2 = component deterioration
H_3 = ship collision
:
:
H_n = storm surge

In the case of bridges, the equation could take the form:

> $P_{\text{bridge collapse}}$ = P(bridge collapse|earthquake of M_X) P(earthquake of M_X) + P(bridge collapse|component deterioration) P(component deterioration) + P(bridge collapse|ship collision) P(ship collision) + P(bridge collapse|storm surge) P(storm surge)

From this, it can be seen that overall risk can be reduced either by reducing the likelihood of an event, (controlling $P(H_i)$) or by designing the system to resist the effects of that event (reducing $P(F|H_i)$ to some acceptable level). Unfortunately, our state of knowledge and technology does not yet offer the option of preventing natural hazards such as earthquakes and storm surges. However, this is not the case with technological or human-induced hazards such as component deterioration or ship/bridge collisions over which we have some control. Even though we do not yet know the precise relationship between say, good maintenance and the structural integrity of a bridge, we can point to examples where a lack of maintenance was a direct cause of failure[4] and, thus, develop a sound business case for preventative maintenance programs.

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[4] The Mianus River Bridge in the State of Connecticut carried Interstate 95. In 1983 a rusted hanger pin and hanger failed and caused a two-lane section of the roadway to fall into the river below resulting in the loss of three lives. Excessive rust had developed due to paved over road drains and went unobserved because of poor inspection practices (NTSB 1984). The Schoharie Creek Bridge, which carried the New York State Thruway, failed in 1987 after a pier was undercut by scour and fell into the creek. The bridge girders slipped off their supports and caused a section of the roadway to fall into the creek, killing 10 people. Despite a report almost 10 years earlier calling for replacement of missing riprap around the failed pier, the work was deleted from a maintenance contract and the bridge foundations were not regularly inspected (NTSB 1988).

What are the consequences?

The consequences of a hazardous event vary by type and intensity. They include loss of life and severe bodily injury including the economic value of premature death. Direct economic losses are the damage to systems and the cost to repair or replace them. Secondary economic losses arise from lost income because businesses are disrupted or forced to close. For example, the total direct and indirect economic losses for the September 11 attacks in New York exceeded $38 billion (Dixon and Stern 2004) and a "best guess" value of more than $100 billion has been assigned by many sources to the damages caused by Hurricane Katrina. Other, less quantifiable, consequences of hazards include human suffering and environmental damage. However, even if all potential consequences could be determined *a priori*, finding a common parameter to measure them is challenging indeed. Most often, losses are couched in economic terms, although this is more a matter of convenience in calculation than a belief that a single value can capture the full impact of a hazardous event.

Risk Management

Although the risk assessment process is useful because it identifies those situations that demand priority attention, it provides little insight into what countermeasures or other mitigation strategies might be most appropriate in a specific application. For this, risk management is necessary. *Risk management* builds on the risk-assessment process by seeking answers to a second set of questions (Haimes 1991):

> *What can be done and what options are available?*
> *What are the associated trade-offs for all costs, benefits, and risks?*
> *What are the effects of current management decisions on future options?*

What can be done and what options are available?

Options for managing the risk to infrastructure from multiple hazards include the following:

- Avoid the risk by locating somewhere else. (This is not always an option for the infrastructure industry, which is usually place-based.)
- Reduce the risk by taking countermeasures (reducing $P(F|H_i)$).
- Spread the risk by choosing multiple redundant locations for certain activities. (Following the 9/11 attacks, the New York Stock Exchange and many businesses in New York and elsewhere have taken this approach.)
- Transfer the risk by buying insurance. (The viability of this option will depend on the continued willingness and ability of the insurance industry to underwrite hazard risk at rates that the industry is able and willing to pay. An emerging market in Catastrophe Bonds may also provide additional capital to provide surety against loss.)

- Retain the risk. (In light of the preceding points, infrastructure owners may have no choice but to accept a portion of the consequences of the multiple hazards they face.)

What are the associated trade-offs for all costs, benefits, and risks?

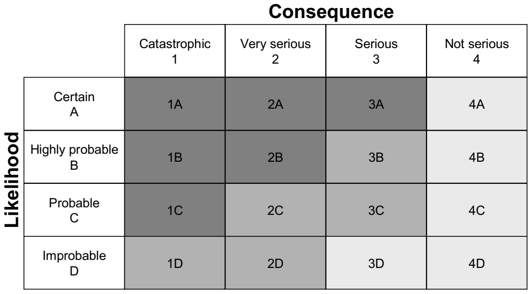
Those responsible for protecting civil infrastructure must also consider the cost of providing a specified level of protection. The cost that must be considered is not only the direct economic cost of protective features but also the lost opportunity cost of the invested capital. Ultimately, a choice must be made whether an investment nominally to reduce risk to those potentially affected is of greater benefit than expending the funds for some other purpose. For example, is it better public policy to increase seismic resistance or use the funds for education or healthcare? Because of the difficultly in determining precisely the likelihood of occurrence of a given hazard, and hence the risk, guidelines and standards for infrastructure protection (where they exist) tend to emphasize reducing the vulnerabilities of various infrastructure elements to extreme loadings from hazardous events. If an appropriately designed system is stressed, the likelihood of adverse consequences ($P(F|H_i)$) will be reduced. However, these features will be effective only if the threat and design intersect. Although prudent when resources are readily available or a devastating event so likely that society demands a response, some economic scrutiny is justified.

What are the impacts of current management decisions on future options?

Economists and social scientists use *path dependence* to describe situations where the future is shaped by past events, not just current conditions, and much of our basic infrastructure exhibits such path dependency. So, in thinking strategically about how best to ensure that service is maintained over a range of hazards, we need to keep today's decisions in perspective with the trillions of dollars we've already invested in the infrastructure systems we have. Although the automobile may be a grossly inefficient way to move people and levees a risky way to provide flood control, unless we come up with some radically different ideas about how we'll live in the future, today's infrastructure will be around for a long time and needs to be protected. At the same time, most of the infrastructure we strive to protect is based on models from the 18th and 19th centuries and an engineer from the Roman Empire would probably have little difficultly understanding our current water and highways systems. Because of this, we need to devote at least some thinking about how we might transition to the infrastructure of the future and not allow the reality of path dependence to become a self-fulfilling anchor to the past.

Using Risk in Decision-Making

Figure 9.1 is a simplified decision matrix that categorizes actionable outcomes of the risk assessment process based on the probabilities of certain classes of events and their consequences. Predictably, high probability events with adverse outcomes demand



Likelihood	Consequence Catastrophic 1	Very serious 2	Serious 3	Not serious 4
Certain A	1A	2A	3A	4A
Highly probable B	1B	2B	3B	4B
Probable C	1C	2C	3C	4C
Improbable D	1D	2D	3D	4D

Figure 9.1. Probability/Consequence Matrix for Evaluating Risk Levels

priority attention while lower probability or consequence events can be dealt with less urgently. Although this is useful information, it provides little insight into what actions might be most appropriate in a specific situation because every potential option provides some relief and carries some cost.

Whether or not a particular action is cost effective requires that we know the expected magnitude of the loss that will be avoided compared to the cost of avoiding that loss. Therefore, the cost (C) of a management strategy should be less than the total discounted value of the expected benefits over the period of interest (Kunreuther 1998), or

$$C < \sum_{t=1}^{T} (p-p^*)(L)/(1+r)^t$$

where

p = probability of loss w/o strategy
p^* = probability of loss with strategy ($p^* < p$)
L = loss reduction from risk management strategy
r = annual discount rate
T = time horizon for evaluation

So, if the probability of an expected loss of $50 million can be reduced from a once in 50 year occurrence ($p = 0.02$) to once in 200 years ($p^* = 0.005$), the total discounted value ($r = 0.03$) (OMB 2007) of the benefits during a 20-year period is just over $11 million. Thus, any cost of a risk management strategy less than this amount makes economic sense, and the cost effectiveness of alternative strategies can be determined on a common basis.

Some Final Thoughts

The foregoing discussion assumes that the relationships between events and outcomes are sufficiently well understood to permit the development of rational risk management strategies. However, all too often the event chain leading up to adverse consequences is truncated prematurely so that the true cause of a failure is missed in the subsequent

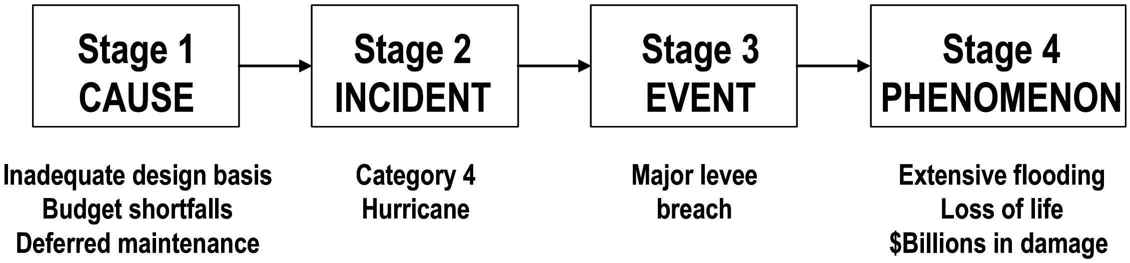


Figure 9.2. Event Chain for the Flooding of New Orleans

failure analysis. Figure 9.2 depicts an event chain for the devastation of New Orleans following Hurricane Katrina in 2005. If we only concentrate on the levee breach that caused the flooding or the hurricane that precipitated it, the root causes of inadequate design and deferred maintenance driven by a lack of resources can easily be overlooked and the system primed for a future recurrence. In a study of industrial accidents, Kletz (2001) also cautions about too much emphasis on apparent causes:

> If we talk about causes we may be tempted to list those we can do nothing about. For example, a source of ignition is often said to be the cause of a fire. But when flammable vapor and air are mixed in the flammable range, experience shows that a source of ignition is liable to turn up, even though we have done everything possible to remove known sources of ignition. The only really effective way of preventing an ignition is to prevent leaks of flammable vapor. Instead of asking, ‘What is the cause of this fire?’ we should ask ‘What is the most effective way of preventing another similar fire?’ We may then think of ways of preventing leaks.

Care needs to be taken in analyzing past failures so that proposed solutions address the real issues, not merely the obvious ones. For example, in the aftermath of September 11, there was much public demand to change building code provisions regarding structural collapse (Lipton and Glanz 2002). However, the connection between airplane impact and the collapse of the World Trade Center, although valid, gets caught in Kletz’s obvious cause trap and rather misses the point. Instead of asking, “How can we design buildings so that they will not collapse if deliberately struck by an airplane?” perhaps the more appropriate question is, “How can we protect tall buildings from similar attacks?” The answer to the second question lies at least as much with airport security as with structural design and building codes. Following Kletz’s admonition, perhaps the real question is not, “What are the best technologies to resist terrorist attack?” but rather, “How can we reduce casualties in the event of an attack?” This is a fundamentally different question (Little 2004).

The Limits of ‘‘Protective’’ Technology

History is littered with accounts of allegedly foolproof or failsafe protective technologies that failed spectacularly when tested. The ‘‘unsinkable’’ *Titanic* and the ‘‘impregnable’’

Maginot Line added new terms to the lexicon of failure. Their designers assumed what was believed to be a rational threat scenario, then planned and designed for it, yet both failed utterly in practice. The damage limits for the *Titanic* turned out to have no basis in reality—the iceberg that damaged the ship did not know that the design assumed that only a certain number of compartments could be compromised. In World War II, the Germans simply chose not to confront the extremely formidable defenses on the French border and attacked through lightly defended Belgium instead. Despite this, a questionable reliance on protective technology continues. The Karpun tunnel fire in Austria that claimed 155 lives in 2000 started in a train believed to be fireproof. An assessment of the event noted the following:

> In November 2000, a supposedly ‘‘fireproof’’ train in a tunnel in the Austrian Alps caught fire and led to the deaths of 155 people. While many factors contributed to the disaster, one of them was thinking that a vehicle can be fireproof (Carvel 2002).

More recently, although more than $2 billion was spent on security upgrades at the World Trade Center following the 1993 bombing (Karpiloff 2000), none of these features was effective against the attack that actually occurred.

The Need for Stakeholder Involvement

Despite a continually expanding knowledge base regarding the nature of various hazards and their likely impacts, implementing effective risk reduction strategies is not a straightforward technical exercise. Although people expect infrastructure of all types to survive an extreme event and services to be delivered in the aftermath, no consensus exists on how this can best be achieved. The government and system owners clearly have a responsibility to provide for continuity of services. However, when considering appropriate reliability levels for infrastructure systems and the means of providing it, the cost must also be considered. Many responses to the risk of natural and other hazards are driven more by the desire to protect people and assets from what could happen rather than what is likely to happen. In other words, these measures address the *vulnerability* of people and assets to certain types of events and are not necessarily a true assessment of the *risk* of that event to a particular system. This approach essentially removes the public from the decision-making process and eliminates from consideration any willingness on their part to accept some portion of that risk. Given the cost of providing routine services and the competition for funds in the public and private sectors, this is a policy discussion that should be informed by sound risk management principles and reasonably should include representatives of the public at-large and not be limited to just government agencies and system owners.

Conclusion

We will never be able to anticipate all possible threats to civil infrastructure, and even if we could, there is not enough money to deploy technologies to address them. Our approach to managing risk needs to be flexible, agile, and capable of addressing new threats as they emerge. Technology has a key role to play in keeping infrastructure functioning but only if supported by the organizations and people who can develop pre-event strategies, manage the response to an extreme event, and hasten recovery after it occurs. Investments in emergency response technologies, strategies, and organizations have the potential to be particularly cost-effective because they are not tied to a place or a single event. The ancillary benefits from such holistic investments are that these organizations and people will be available to deal with a broad range of natural disasters or other, yet unanticipated, crises should they occur. Well-designed and maintained infrastructure systems are likely to recover as quickly following an earthquake, landslide, or flood as a terrorist attack, as well as providing better service throughout their lifetimes.

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The "Unknown" Seismic Hazard in East Tennessee and Potential Losses

Christine A. Powell[5] and James E. Beavers[6]

Introduction

Earthquake activity is synonymous with plate boundaries yet, active zones of seismicity do occur within plate interiors. Perhaps the best-documented intraplate seismic zone is the New Madrid seismic zone (NMSZ) in the central United States. Abundant evidence indicates that the NMSZ generated at least three major earthquake sequences in the past (1450, 900, and 1811-1812 AD) with a 400-500 year recurrence interval (Kelson et al. 1996; Tuttle and Schweig 1995; Tuttle et al. 2002; Tuttle 2005). The 1811-12 sequence was felt over the entire eastern United States and produced extensive damage in the (then) sparsely populated Mississippi embayment. Another, well-defined seismic zone exists approximately 500 km southeast of the NMSZ and covers eastern Tennessee and portions of northern Alabama, western North Carolina, and northwest Georgia as shown in Figure 9.1. This zone, called the eastern Tennessee seismic zone (ETSZ), receives little publicity and is virtually unknown to the general population. Although the ETSZ generates approximately 50 recorded earthquakes each year, none has exceeded magnitude 4.6 in recorded history. How dangerous is the ETSZ? Should it be viewed as an annoyance or as a potentially lethal source of ground shaking? This paper presents the known facts concerning the ETSZ and concludes that the zone should command much more respect than it is currently afforded.

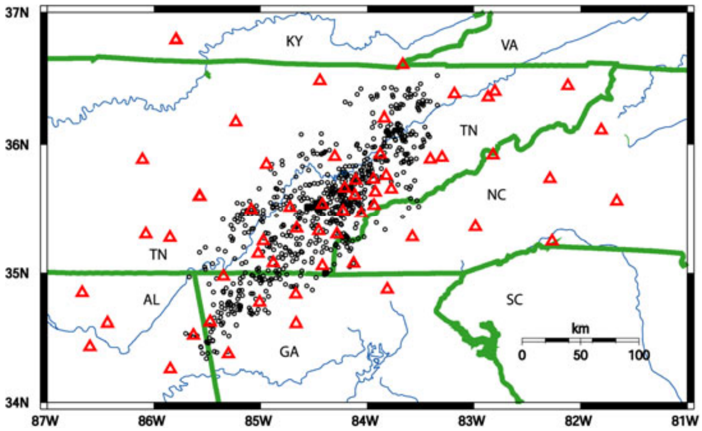

Figure 9.1. Seismicity in ETSZ 1980-2002. The triangles are seismic stations and the small circles are epicenters.

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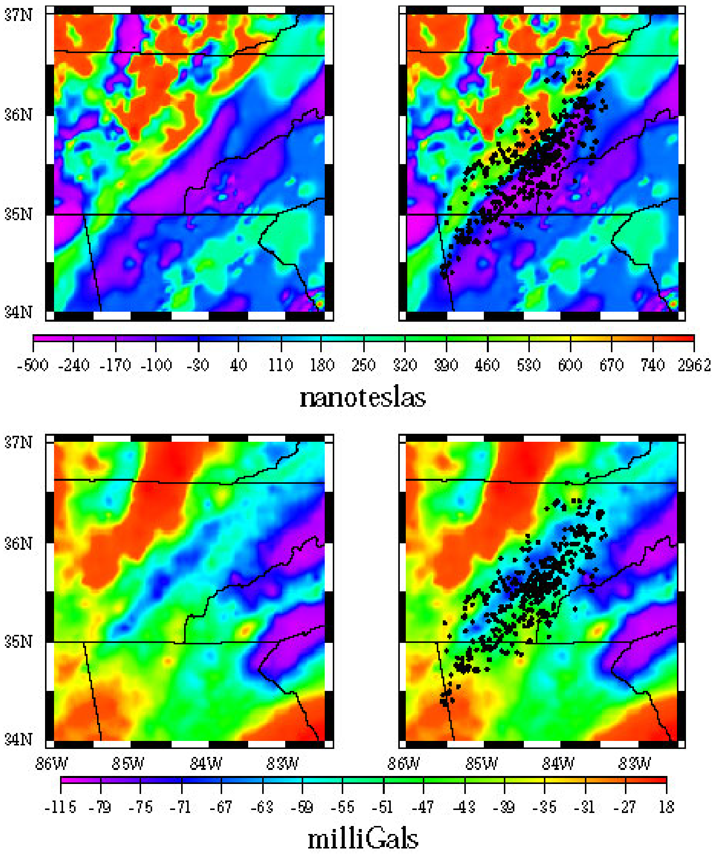


Figure 9.2. Magnetic and Bouguer Gravity Data with Earthquake Epicenters in the Southern Appalachian region. The NY-AL magnetic lineament is indicated by the abrupt change from high magnetic values to low values extending from the Southwest to the North East through Eastern Tennessee.

Background

The ETSZ is approximately 300 km long and 50 km wide and is located in the Valley and Ridge physiographic province of the southern Appalachians. Earthquakes occur in basement rocks below the major Appalachian thrust sheets, at depths ranging from approximately 5 to 26 km (Vlahovic et al. 1998). There is no indication of surface faulting associated with the zone, although Whisner et al. (2003) called attention to several disturbed localities that could have been caused by seismic activity. Rather, the ETSZ trends at an angle to the dominant trend of Valley and Ridge structures. Evidence that the seismicity is linked to ancient basement structure is provided by the clear association of the ETSZ with prominent, long-wavelength potential field anomalies. Specifically, the ETSZ follows the trend of the New York–Alabama (NY-AL) magnetic lineament and associated long-wavelength gravity lows shown in Figure 9.2.

Several studies have shown that the NY-AL magnetic lineament is associated with a major structural boundary in Grenville-age basement rock (King and Zietz 1978; Kaufmann and Long 1996; Vlahovic et al. 1998). Instrumental monitoring of the ETSZ began about 20 years ago and the accumulated arrival time data have been used to obtain detailed velocity images of the crust (Kaufmann and Long 1996; Vlahovic et al. 1998), focal mechanism solutions (Chapman et al. 1997), and improved, relative hypocenter locations (Dunn and Chapman 2006). Gravity and magnetic potential field data have been investigated extensively by Vlahovic (1999).

Faulting and Earthquake Potential

Insight into the orientation of faults and surface rupture in the basement can be obtained by determining earthquake focal mechanism solutions. Focal mechanisms use recorded seismic waveforms to specify the orientation and slip on the fault surface. One limitation is that focal mechanisms cannot distinguish between the true fault plane and motion on a second plane perpendicular to the fault plane and normal to the direction of slip across the fault. In the ETSZ, focal mechanisms indicate that strike-slip motion on steeply dipping planes is the dominant mode of faulting throughout the entire seismic zone (see Figure 9.3) (Chapman et al. 1997). Most faulting here involves right-lateral strike-slip motion on N-S trending planes or left-lateral motion on E-W trending planes. These fault motions are consistent with the northeast maximum compressive stress direction for North America as a whole (Zoback and Zoback 1991). Note that these fault trends do not align with the overall NE-SW trend of the seismic zone. An explanation for this discrepancy was provided in Powell et al. (1994), which suggested that the trend of the seismic zone is controlled by basement structure while earthquake activity is a response to present day stress orientations. A small, but significant, population of fault plane solutions indicates right lateral motion on NE-SW trending planes or left-lateral motion on NW-SE trending planes. The NE-SW trend parallels the seismic zone. The consistency of fault motions is remarkable and suggests the presence of an organized set of basement faults.

Distinguishing between the two possible fault planes in focal mechanism solutions requires independent evidence of rupture direction. Chapman et al. (1997) conducted an independent analysis of statistically significant alignments of juxtaposed epicenters to determine the most likely directions of fault motion in the ETSZ. The distribution of epicenters shows significant clustering in the NE and EW directions; these directions also represent the most often observed slip directions in the focal mechanism solutions and were interpreted as the strike directions of basement faults. The dominance of east-west tending seismogenic faults was also demonstrated in a relocation of ETSZ hypocenters using the double-difference location algorithm (Dunn and Chapman 2006).

An estimate of the earthquake magnitude that would result from slip along a fault as a function of fault length or fault area can be obtained from empirical formulas based upon ground rupture observations (Wells and Coppersmith 1994). Wells and Coppersmith (1994) developed the following equation to determine magnitude based on fault length:

$$M = 5.16 + 1.12\log(L)$$

where M is moment magnitude and L is the fault length in km.

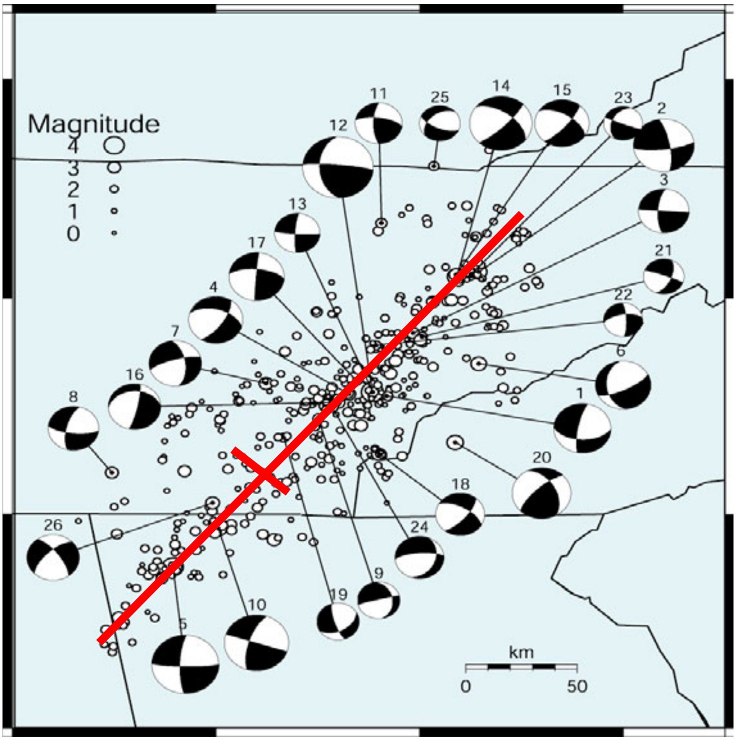
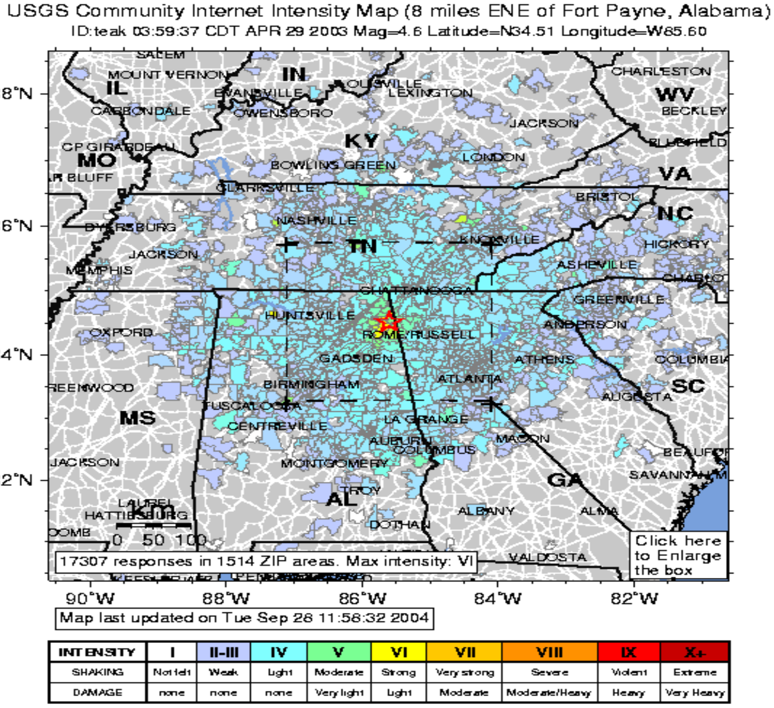


Figure 9.3. Lower Hemisphere Focal Mechanisms for 26 Earthquakes with Potential NE 300 km and/or EW 30 km Fault Trending Fault Planes. The number next to each focal mechanism refers to the specific earthquake analyzed and the size of the mechanism provides an indication of the relative magnitudes of the earthquakes (larger size means greater magnitude).

Let us suppose that the major basement faults trend NE, parallel to the seismic zone as shown by the long solid line in Figure 9.3. In this case, slip could occur along the entire 300 km length of the seismic zone and, using the above equation, could produce a moment magnitude 7.9 earthquake. This represents a maximum size event. However, even if slip occurs in an E-W direction, a fault length of about 30 km is indicated by juxtaposed epicenters (Chapman et al. 1997). Slip along a 30 km fault length would produce a moment magnitude 6.8 earthquake. An earthquake of this magnitude would still result in massive damage and loss of life as discussed as follows.

An indication of the widespread damage to be expected from a magnitude 6.8 earthquake can be obtained from empirical formals that relate felt area to magnitude. Johnston (1996) developed earthquake moment versus felt area regressions specifically for eastern North America. According to these formulas, the felt area for a magnitude 6.8 earthquake is approximately 4×10^6 km^2 while the area involving structural damage is approximately 1.5×10^4 km^2. The felt area produced by the comparable 1895 New Madrid seismic zone earthquake can be found in Hopper and Algermissen (1980). These large felt and damage areas indicate that a significant ETSZ earthquake would affect a huge population and disrupt transportation and communication systems as well as TVA facilities. Figure 9.4



INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

Figure 9.4. Damage and Felt Area of April 29, 2003 Magnitude 4.6 Fort Payne, AL, Earthquake.

shows the felt area for the largest instrumentally recorded earthquake in the ETSZ: the April 29, 2003 magnitude 4.6 Fort Payne, Alabama event. This moderate earthquake generated the most felt reports for any event in the United States outside of California and ranks sixth overall in reported events nationwide (*http://pasadena.wr.usgs.gov/shake/cus/top_ten_list.html*).

Clearly, the ETSZ has the potential to produce a devastating earthquake and deserves careful consideration in any hazard evaluation for the region.

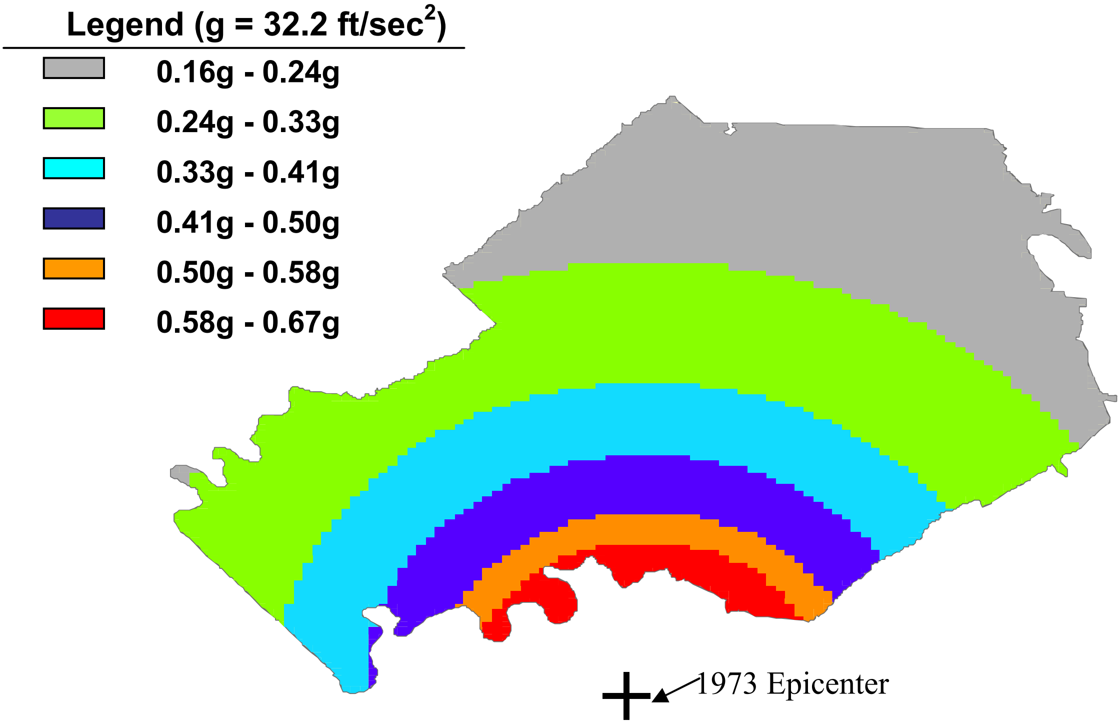
Potential Losses

With the development of the loss estimation methodology Hazard U.S. Multihazard (HAZUS-MH) by the Federal Emergency Management Agency (FEMA 2006) any of the central states can examine their potential losses from scenario earthquakes. All they have to do is pick a scenario earthquake by location and magnitude. The recent Fort Payne, AL, event was previously mentioned, but on November 30, 1973 East Tennessee also had a 4.6 magnitude event in Blount County, TN, at latitude 35.80^{o} and longitude -83.96^{o} (Bollinger et al. 1976). The largest population center nearest to the event was Knoxville, TN, in adjacent Knox County. In 2006 the population of Knox County was estimated at 411,967 (Census Bureau 2006). The 1973 4.6 earthquake resulted in minor damage to many homes and structural damage to the University of Tennessee hospital emergency room (KNS 1973), which was 16 km from the epicenter.

HAZUS-MH is programmed to only handle earthquakes of magnitude 5.0, or above, since magnitude 5.0 and above is typically where structural damage occurs to buildings. HAZUS-MH calculates building-related losses into two categories: direct building losses and business interruption losses. If one assumes a magnitude 5.0 occurs at the epicenter of the magnitude 4.6 1973 earthquake, the building related losses in Knox County alone would be $262.4 million. The 1973 event occurred at 2:00 a.m. If the scenario event also occurred at 2:00 a.m., the HAZUS results show that 23 and 3 people would receive Level 1 and Level 2 casualties (injuries), respectively. There were no Level 3 or 4 casualties (serious injury or death). These results seem reasonable based on the second author's experience during the 1973 event.

As previously noted, referring to a magnitude 6.8 earthquake at the epicenter of the 2003 Fort Payne, AL, event, an earthquake of this magnitude would still result in massive damage and loss of life. As a result, the authors ran a magnitude 6.8 earthquake scenario event at the epicenter of the 1973 magnitude 4.6 earthquake. This scenario resulted in ground motions in Knox County ranging from a peak ground acceleration (PGA) of 1.09g down to 0.26g for an average of 0.68g. Using the USGS JAVA calculator (USGS 2007), and calculating the hazard curve for Knox County (latitude 35.99^{o} and longitude -83.92^{o}) (Google 2007) shows a PGA of 0.68g has the probability of being exceeded about once every 7,400 years. Thus, a magnitude 6.8 event in the ETSZ would be extremely rare and a magnitude 7.9 would be even more rare, because the rupture would have to be 300 km (the 1906 San Francisco earthquake ruptured the San Andreas fault 296 km). As a result, the authors chose a scenario earthquake event that is a more credible (realistic) event for the ETSZ of magnitude 6.0. Such an event would only require 5.6 km of fault rupture. One could consider the scenario earthquake losses to Knox County as indeed massive damage and loss of life. The total building related losses would be $2.4 billion (10 percent of the Knox County building inventory value) with Level 1, 2, and 3 casualties for a 2:00 p.m. event of over 2,000 and with Level 4 casualties (deaths) totaling 73. Of the 128 schools in Knox County 46 would experience more than 50 percent damage. Such an event anywhere along the ETSZ would result in massive damage and loss of life. Keep in mind that building related losses would not be the only losses; there would be infrastructure losses. For this event these losses would represent about $0.5 billion

The ground motions in the magnitude 6.0 scenario event across Knox County ranged from a high of 0.67g to a low of 0.16g as shown on the ground motion contour map in Figure 9.5, with an average of 0.42g. Again, from the USGS JAVA calculator and doing some interpolation a ground motion in Knox County of 0.42g has the probability of being exceeded in one year of 2.716E-04 or about 1.5 percent in 50 years which is close to the maximum considered earthquake defined as having a 2 percent chance of being exceeded in 50 years (2500 year return period) used by the International Building Code for developing seismic design criteria (IBC 2003).



Ground motion of an arbitrary magnitude 6.0 earthquake at the epicenter of the 1973 East Tennessee earthquake magnitude 4.6

Figure 9.5. Ground Motion Contours Across Knox County.

Although the probability of such an event is still low, unfortunately such events can happen. For example, Newcastle, Australia, experienced a magnitude 5.6 earthquake in 1989 with the epicenter in downtown. At the time, Newcastle had a building code with seismic zone as zero. This relatively small earthquake damaged more than 60,000 buildings and resulted in 13 deaths (Jacandra 1989). The economic losses from that earthquake were about $1 billion Australian dollars (Dhu and Jones 2002) or $0.8 billion in U.S. dollars ($1.3 billion in today's U.S. dollars).

Conclusions

It is evident that the ETSZ as currently understood represents a significant risk to the population and should be treated with more respect. More seismological research needs to be conducted on the ETSZ to determine whether the zone is capable of producing a magnitude 6.0, 6.8, or even a 7.9. A magnitude 7.9 would be catastrophic to the region. In the meantime the International Building Code should be the code of record for all those counties in the states of Alabama, Georgia, North Carolina, and Tennessee that are in and adjacent to the ETSZ.

Acknowledgement

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Frequency of Hailstorms and the Resulting Damage in the Central United States[1]

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The opinions expressed in this paper are those of the authors and do not necessarily reflect the opinions of State Farm Insurance Companies® and its affiliates.

Abstract

Hail is a peril that threatens all but a handful of areas in the United States and may necessitate the premature replacement of roofs. Between 1995 and 2005, the country averaged about 11,000 hailstorms per year. Of the 20 most costly insurance losses in 2005 (global), four involved hail. Combined wind/hail losses from these four, U.S. hail events totaled more than $1.5 billion. Newer homes have larger roofs. This, and the increasing number of households in high hail-risk locations, translates into more roof area being exposed to damage. One alternative to minimizing damage is to use impact resistant roofing materials. State Farm Insurance Companies continues to review options for their policyholders to mitigate repeated and significant homeowners' hail losses. Since it is unlikely that hailstorms can be prevented, damage reduction efforts have been focused on improving roofing material impact resistance.

Introduction

While the meteorological community has focused on understanding where, why, and when hailstorms occur, historically it has been left to the insurance industry to quantify how this natural hazard affects our society. Damage from hailstorms can severely affect the built environment, personal property, and the agricultural industry.

Infrequently, large hail has been known to inflict injuries to people and even cause death. In 1979, a child was killed in Fort Collins, CO, when struck on the head by a large hailstone (hail in this storm averaged 7.5 to 10 cm [3 to 4 inches] in size). Death and injury of livestock is common (Doesken 1994).

Hail is a peril that threatens all but a handful of states in the United States. Hailstorms typically occur east of the Rocky Mountains with the most frequent and severe storms occurring in the Great Plains states. Hailstorms do not strike all areas equally; severe hailstorms are most frequently reported in eastern Colorado, Wyoming, and Montana,

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and throughout the states of Kansas, Oklahoma, Nebraska, and Texas but can and do occur throughout the Central United States (Changnon, S. A., unpublished manuscript 1998).

It is not the purpose of this paper to investigate the meteorological aspects of the hail peril, though weather data is provided. Rather, the focus is to provide a perspective on the financial impact of hailstorms and the resulting physical damage in the Central United States through the use of homeowners' policy insurance loss statistics and an exploration of related mitigation programs.

There is an important difference between meteorological frequency and insurance loss frequency. If hail falls in an area where there are no insured structures or vehicles, or before crops have been planted (insured subjects at risk), the event will not be recorded in insurance loss records. This point should be remembered throughout this paper.

Hail Events in the United States

During the past decade (1995–2005), the United States has averaged more than 11,000 hailstorms a year (storms generating hail greater than 1.9 cm (0.75 inch)) (NWS SPC). The four most active states (Kansas, Texas, Oklahoma, and Nebraska) account for more than one-third of all reported hail events. Texas and Kansas each experience an average of more than 1,400 events per year (2000–2005), while Nebraska averages a little over 800 and Oklahoma almost 800. The National Weather Service only collects data on severe thunderstorms, which are defined as thunderstorms which produce hail 1.9 cm (0.75 inches) in diameter or larger, and/or that have wind gusts reaching 93 kilometers per hour (58 mph) or greater, and/or a tornado.

The number of reported hail events has steadily increased over the past half century (Figure 10.1). This is thought to be due to improvements in tracking technology and not actual increases in the frequency of hailstorms. The advent of Doppler radar (fully deployed by 1996 [Mitchell 2005]), which can remotely identify hailstorms, has given the National Weather Service (NWS) an invaluable tool with which to record and chronicle hail events. In the past it was suspected that rural hailstorms were under-reported, especially in states that have large unoccupied areas. It has been recognized that in heavily populated areas the tendency has been to see numerous events reported to the NWS, which are potentially from the same hailstorm and appear to skew hail data (Dane County 2004). Doppler radar technology enables a greater understanding of the true frequency and hail potential thereby supporting a demonstrable need for building methods and materials designed to resist hail damage.

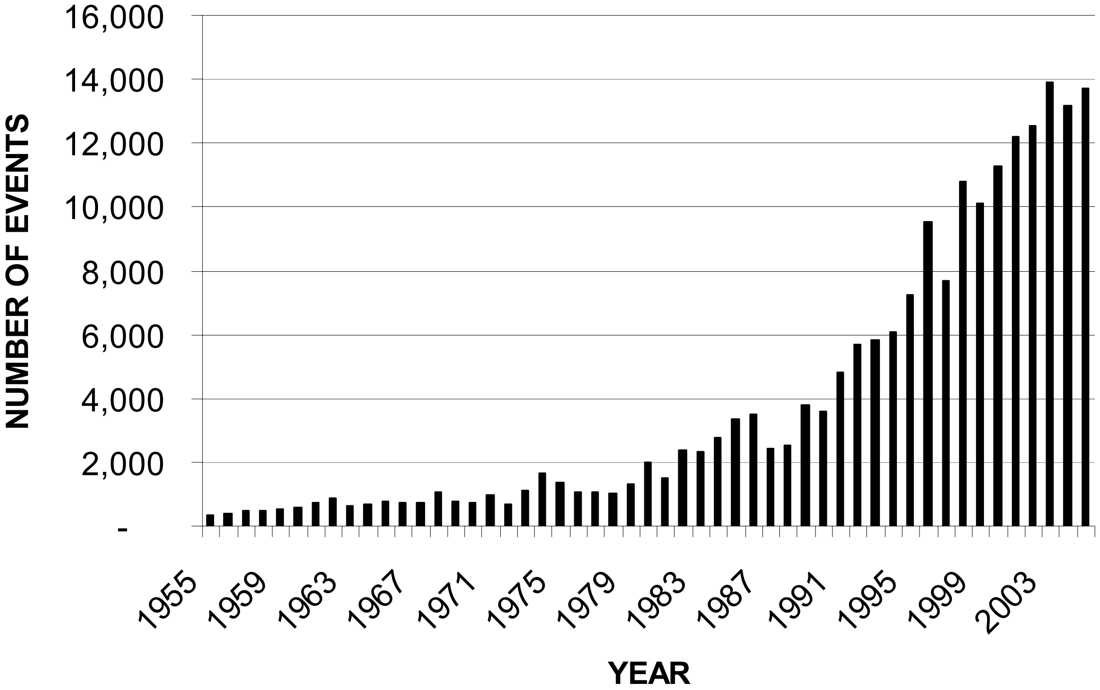

Figure 10.1. Hail Events 1955–2005 (National)
Data Source: NOAA's National Weather Service Storm Prediction Center

Texas officials estimate that up to 40 percent of all Texas homeowners insurance claims result from hail damage, and in Colorado, it is estimated that up to 50 percent of "homeowners' insurance premium may be going toward hail and wind damage costs" (RMIIA 2007). While hailstorms occur most frequently in the Midwest and Great Plains states, Colorado has the most storms with large-size hail (diameter greater than 3.81 cm [1.5 inches]). Though Colorado statistically has fewer storms per year, (just over 400 reported per year from 2000 to 2005) the storms that do occur tend to cause more damage due to the larger size hailstones (Doesken 1994) (RMIIA 2007).

Hailstones can become quite large. The largest one ever recovered fell in Aurora, NE, in 2003. It was more than 17.78 cm (7 inches) in diameter with a circumference of 47.625 cm (18.75 inches). Since it was not weighed at the time, the 1970 Coffeyville, KS, hailstone is still officially considered the largest hailstone on record. The Coffeyville stone had a diameter of 14.4 cm (5.67 inches), a circumference of 44.45 cm (17.5 inches), and a weight of 757.5 grams (1.67 pounds) (NOAA) (NSLL).

A hailstorm usually strikes a relatively narrow geographical area (termed a *hail swath*). These swaths can range in size from a few hectares to an area of +/- 15 kilometers (+/- 10 miles) wide and +/- 150 kilometers (+/- 100 miles) long. Piles of hail in these swaths have been reported so deep that a snowplow was required to remove them. Occasionally, even hail drifts occur.

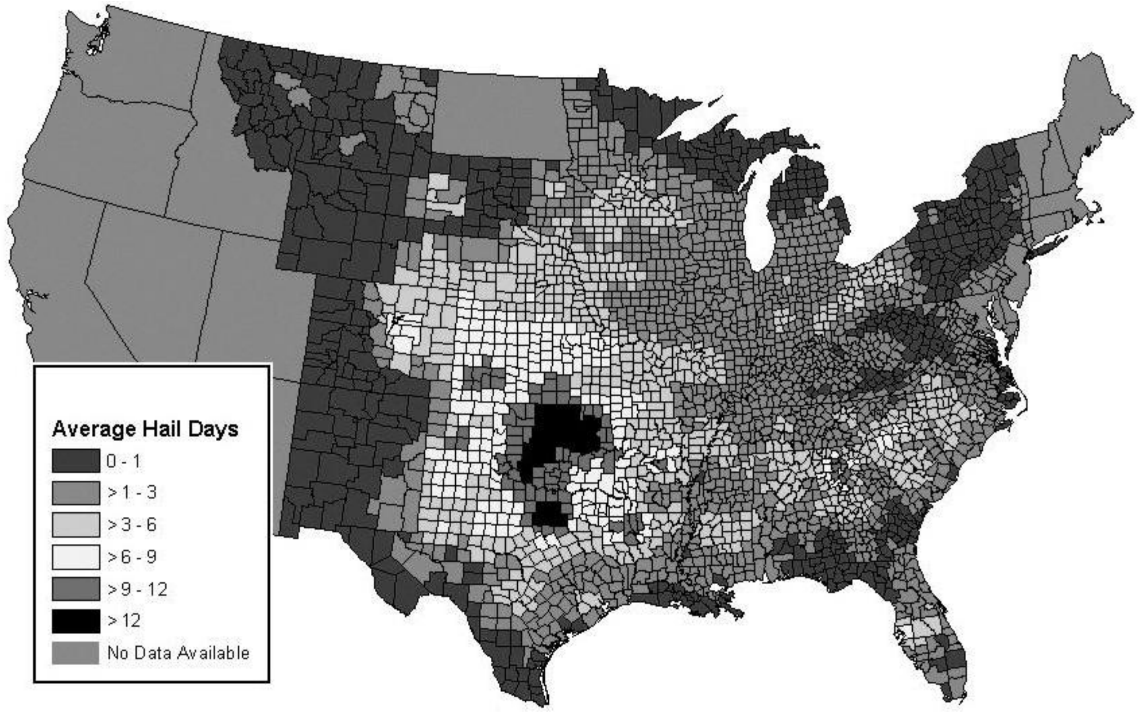

Figure 10.2. Average Number of Hail Days with Damaging Hail (Greater than 1.9 centimeters [.75 inches]) *Source: IBHS*

Hailstorms, Risk, and Damage

In 1989 insurers estimated that hail caused nearly $2 billion in damage each year (Smith 1994). Among the most expensive disasters that State Farm insureds have faced during the past 25 years, 11 have involved significant damage caused by hail. The company's 12th largest single catastrophic event occurred in 2003 when more than 75,000 of homes were damaged, with nearly $384 million (2003 U.S. dollars) being paid, as the result of a hailstorm that crossed northern Texas. Hail is, therefore, a significant financial risk for the people living in hail-prone locations.

Figure 10.2 shows a hail-fall frequency map developed through statistical analysis of hail reported to the National Severe Storm Laboratory (NSSL) from the early 1950's to the late 1990s. The map was developed to assist in communication efforts regarding the hail hazard (IBHS 2006). Similar risk information is available from NSSL's Web site at *http://www.nssl.noaa.gov/hazard/totalthreat.html.*

Instead of focusing only on extremely large hail, the Institute for Business and Home Safety (IBHS) Engineering Department used this information to review the occurrence rate of damaging hail. They chose to define *damaging hail* as any reported hail that is larger than 1.9 centimeters (.75 inches) in diameter (IBHS 2006). This definition mirrors data collected by the National Weather Service (NWS) on what NWS references as "severe" for thunderstorms that produce hail. The results of other research studies suggest that this threshold is conservative and that hail damage to asphalt shingles can be expected to begin to occur at anywhere from 2.54 centimeters (1.00 inches) to somewhere between 3.8 to 5.1 cm (1.5 and 2 inches) (Marshall, et al. 2002).

Research has indicated that "the extent of damage depends on the nature of the roof system, that is, materials and design as well as the force produced by the impact of falling hailstones … age and surface temperature … may also come into play." (Cullen 1997) Therefore, damageability depends on both the characteristics of the hail (size, shape, density, velocity, and impact angle) and the individual attributes of the roofing material (and substrate) that has been impacted.

The map depicts the expected number of times within 20 years (the assumed average life of a residential roof) that damaging hail will fall within individual counties in the Great Plains, Midwest, and eastern states. It should be noted that the occurrence rates of damaging hail are substantially higher than those of the extreme hail noted above. For example, counties of northern Texas and southern Oklahoma can expect damaging hail to occur upward of 12 to 14 times every 20 years (IBHS 2006).

As can be seen from the map, certain areas can be expected to experience multiple hail events within the useful life of a building. In areas that have a high frequency of severe hailstorms (Kansas, Texas, Colorado), the same buildings/roofs are repeatedly damaged. There are some areas of the nation's hail belt where homes have had to be reshingled two and three times during a 10-year period *—a roof covering replacement frequency* well beyond the expected 15- to 20-year lifespan associated with asphalt shingles.

Frequent and intense hailstorms also occur in areas that have become heavily populated and geographically spread out, such as the Denver and the Dallas-Fort Worth metropolitan areas. As previously noted, the increased number of households in the high-hail area translates into more roof area per square kilometer exposed to hail risk. For instance, the Denver metro area grew significantly during the past decade, averaging 2.1 percent per year from 1996 to 2006. This translates to an average net migration of about 30,600 people *each year* during the 1990s. There is a 5.8 percent projected increase in the number of households for the period of 2004 to 2009 (or more than 57,000 new households) (MDEDC 2007). In terms of new single-family residences, both the Houston, Texas Metropolitan Statistical Area (MSA), and the Dallas-Fort Worth MSA are among the most active of the "Top 50 Metropolitan Areas" (nationally ranked number 3 and 4 respectively, 2005 data) (NAHB 2006).

In addition to these expanding population centers in the hail belt, single-family home sizes have also been increasing. New home size has increased from an average of 140 square meters (1,500 square feet) per home (1970) to an average of 218 square meters (2,349 square feet) in 2004 (NAHB 2006). Larger homes typically necessitate larger roofs to cover them. Additionally, the increased use of pre-engineered manufactured trusses has allowed for greater range of roof styles and the inclusion of many more features such as dormers and turned gables. The NAHB Research Center estimated that the national average roof size (square foot area of footprint including garages and porches) in 2001 was 230 square meters (2,479 square feet) while the average roof size in

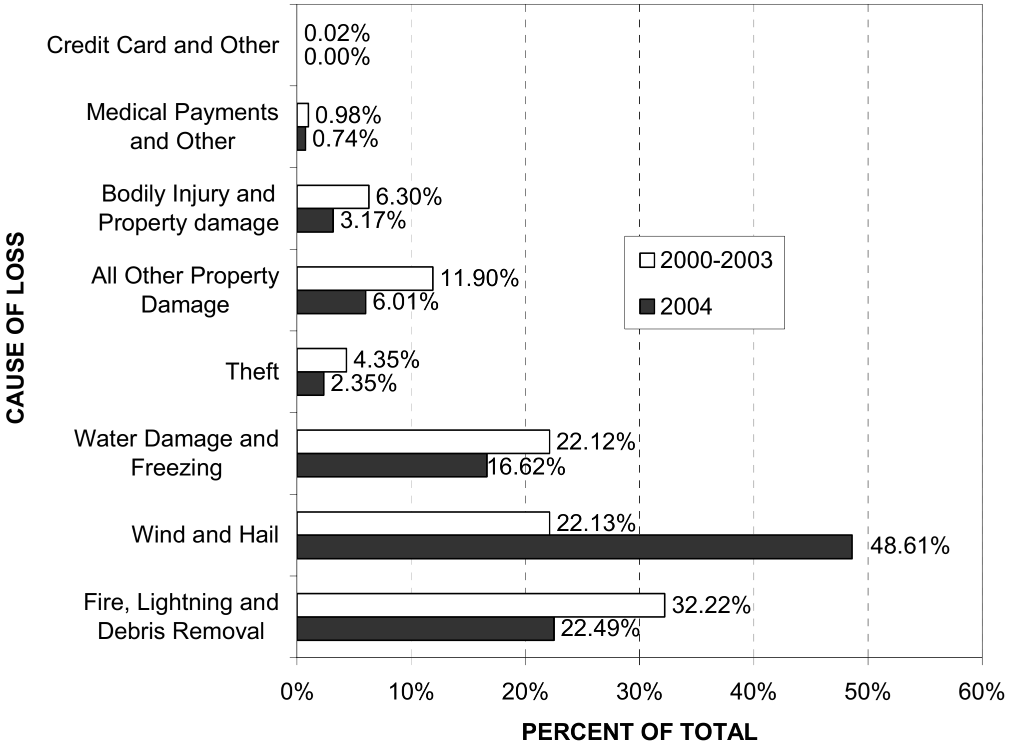

Figure 10.3. Homeowners Insurance Losses by Cause, 2000–2003 (Average) and 2004 (Actual) (Catastrophe and Non-catastrophe) Showing Impact of 2004 Hurricane Season. *Source: III*

the Texas/Oklahoma/Louisiana/Arkansas region (a high hail risk area) exceeded 254 square meters (2,700 square feet) (NAHBRC 2002).

In locations where hailstorms are frequent occurrences, hail damage necessitates the premature replacement of building envelope materials. Replacing roof covering materials before the end of their useful life span creates a financial burden on homeowners, is an inefficient use of natural resources, and wastes space in landfills. The repair or reroofing process can cause an inconvenience for homeowners as they expend time to meet with adjusters and coordinate the work of contractors.

What is the “True Impact” of Hail?

Insurance loss data (III 2007) suggests that wind/hail events account for (on average) more than 22 percent of insured losses (Figure 10.3). As these statistics are for both catastrophic and non-catastrophic losses, this number can vary considerably from year to year depending upon the amount of hurricane activity and, therefore, should be viewed within the context of associated weather events for the time period under consideration. One significant hurricane can cause a substantial rise in the loss percentages, but unlike hurricanes, severe hailstorms occur every year.

For example, on average wind/hail losses constituted only 22.13 percent of losses incurred from 2000 to 2003, but rose to 48.61 percent of losses in 2004 (Figure 10.3). 2004 was the year that Hurricane Charley inflicted more than $7.7 billion dollars, Hurricane Ivan more than $7.3 billion, and Hurricane Frances more than $4.7 billion (all values U.S. dollars indexed to 2005) in insured losses to the United States (III 2007). Clearly, the combined total of these storms, $19.7 billion, contributed to the substantial increase in average annual percentage of losses associated with wind/hail events. Also is should be noted, Hurricane Charley was considered one of the ten most costly *world* insurance losses for the period of 1970 to 2005.

A difficulty arises in analyzing insurance industry hail damage statistics because hail and wind losses are often combined as "wind and hail." There is logic to this classification from an insurance perspective in that the large thunderstorms that generate hail can also produce high winds, covered (insured) wind-driven rain, and have the potential for the development of tornadoes. Therefore, the damage caused by these storms could potentially be from multiple sources and covered by insurance.

When a large event (catastrophe) occurs, there will likely be hail, wind-driven rain, high wind, tree fall, and even tornadic damage occurring within the same geographic area. Since 1997 ISO has defined *catastrophe* as an event that causes $25 million or more in insured property losses and affects a significant number of policyholders and insurers (III 2007). Sometimes all of the causes of loss mentioned above can be found in evidence at one property. Since these causes of damage are typically covered under the usual homeowners' insurance policies, damage from the storm is adjusted and claims are paid for all of the covered building damage associated with the storm—not just hail, not just wind. Consequently, extracting data for "hail only" damage figures is not easily accomplished or normally done, though special studies, such as the IBHS's *Investigation into Insured Losses and Damages to Single-Family Homes Resulting from the April 5, 2003 North Texas Hailstorms*, have been conducted (Smart, J. 2005).

As noted, new homes have increased in size and so have their roofs, which means that when roofs are damaged, claim costs have risen. With material (asphalt shingles contain petroleum products) and labor increases, it is evident that the financial impact of a severe hailstorm in a large metro area can be considerable. The financial implications are substantial as these events generate millions of dollars in claims as well as non-covered costs, such as deductibles or uninsured damage. For example, of the 20 most costly insurance losses in 2005 (global), four involved hail. Note this was the same year that hurricanes Katrina, Rita, and Wilma struck. Combined wind/hail losses from the four U.S. hail events totaled more than $1.5 billion (U.S. dollars indexed to 2005, property and business interruption, excluding liability and life insurance losses) (SwissRE 2006).

To help combat the rising expenses (monetary and non-monetary) associated with the risk of hailstorms, insurance companies have looked for ways to prevent future damage as well as ways to limit the amount of damage when losses occur. The best course, because of its long-term implications, is prevention. Prevention is the elimination of the cause of loss, in this case hail. Unfortunately, it is impractical to eliminate hailstorms, though there have been cloud seeding efforts aimed at reducing or preventing hail; a 1970's era study of the practice by the National Center for Atmospheric Research proved inconclusive (NCAR 1999).

Vulnerable Building Elements

Residential hail damage claims typically include building envelope items such as roof coverings and elements that project from the roof or wall: awnings, skylights, gutters, downspouts, vents, flashing materials, metal chimneys, as well as HVAC units. In addition, wind-driven hail damages siding materials, windows, doors, and fences. As the expense to repair or replace damaged building materials continues to rise, the insurance industry is searching for ways to minimize or mitigate future hail damage.

Roof coverings and siding materials are most often damaged due to their greater percentage of exposure relative to the entire building envelope surface. Roofing damage claims have a higher frequency of occurrence, and therefore, those interested in reducing hailstorm damage to residential structures are addressing roofing vulnerability first. One alternative to minimizing damage is the use of roofing materials that better resists hail damage. Breakthroughs in technology, accompanied with stringent performance benchmarks in standardized testing, have resulted in the identification of impact-resistant roofing products and are contributing to the development of new materials expected to more effectively resist hail damage.

Of the various materials being installed on roofs in the United States, asphalt composition materials are the most widely used type. Unfortunately, like many materials, asphalt composition products are vulnerable to damage from hail. The combination of high market penetration and low resistance to impact damage has over the years contributed to the large number of hail-damaged roofs. Even though in five of the last six years, the asphalt composition product lines (organic, fiberglass, and architectural/laminated) as a whole, have lost overall sales volume or stayed the same, these products continue to dominate sales as they have over the past 18 years (Figure 10.4) (Russo 1988, 1996-2006).

While asphalt composition shingles still accounted for a little more than 80 percent of the roof coverings for new construction in 2001 (NAHBRC 2002), their long dominance means that the majority of existing homes have asphalt composition roofs. Two independent studies (unpublished State Farm study 2004) and a study by IBHS (Smart 2005) came to a similar conclusion about the number of asphalt composition roofs that existed in the Dallas-Fort Worth area in 2003. Approximately 94 percent of the roofs in this region were asphalt composition-type shingles. Hence, studies regarding the field performance of this type of roof covering are important to the understanding of insurance loss severity issues in an area of high hail frequency.

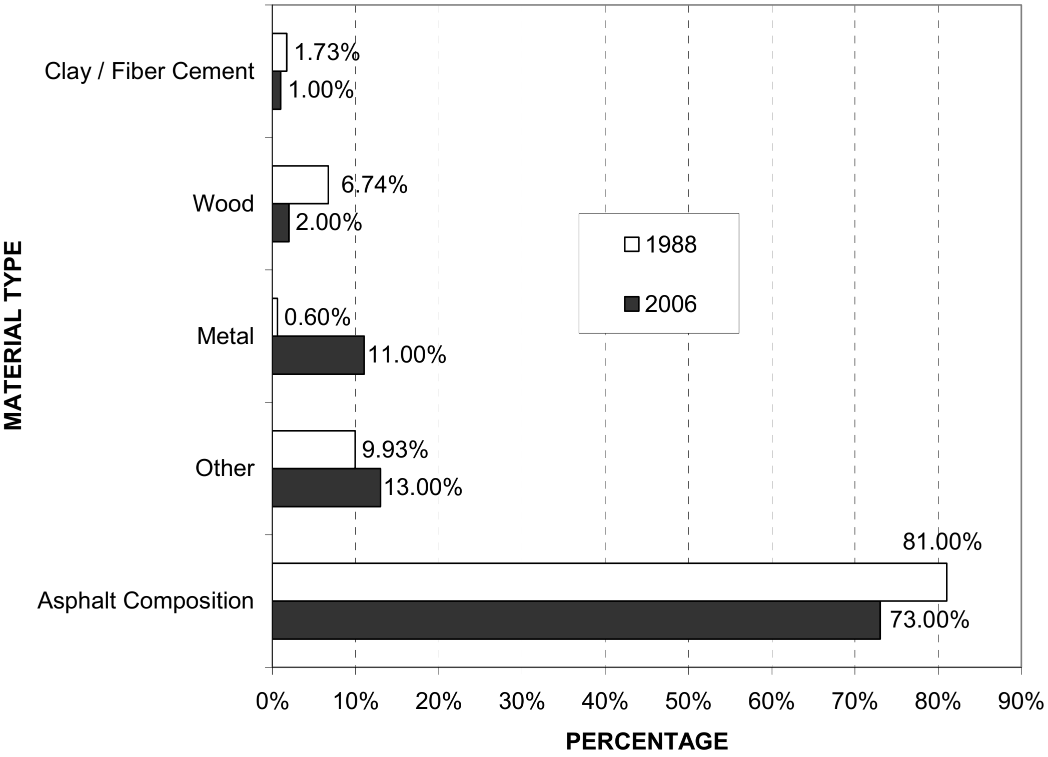

Figure 10.4. Average Roofing Contractor's Volume —All Materials (1988, 2006)
Source: RSI

Since 1988, customer preference has shifted from the three-tab style to the heavier, more textured, dimensional architectural/laminated style (Figure 10.5). Metal products continue to make consistent progress in gaining market share (Figure 10.4) (Russo 1988, 1996-2006). It is unknown if the decline seen in organic asphalt and the net zero gain in wood product volume is due to poor hail performance or changing consumer tastes in roofing materials and/or design. Whatever the reason, this trend is favorable from an insurance risk perspective if it translates into the installation of a higher percentage of impact resistant roofing products.

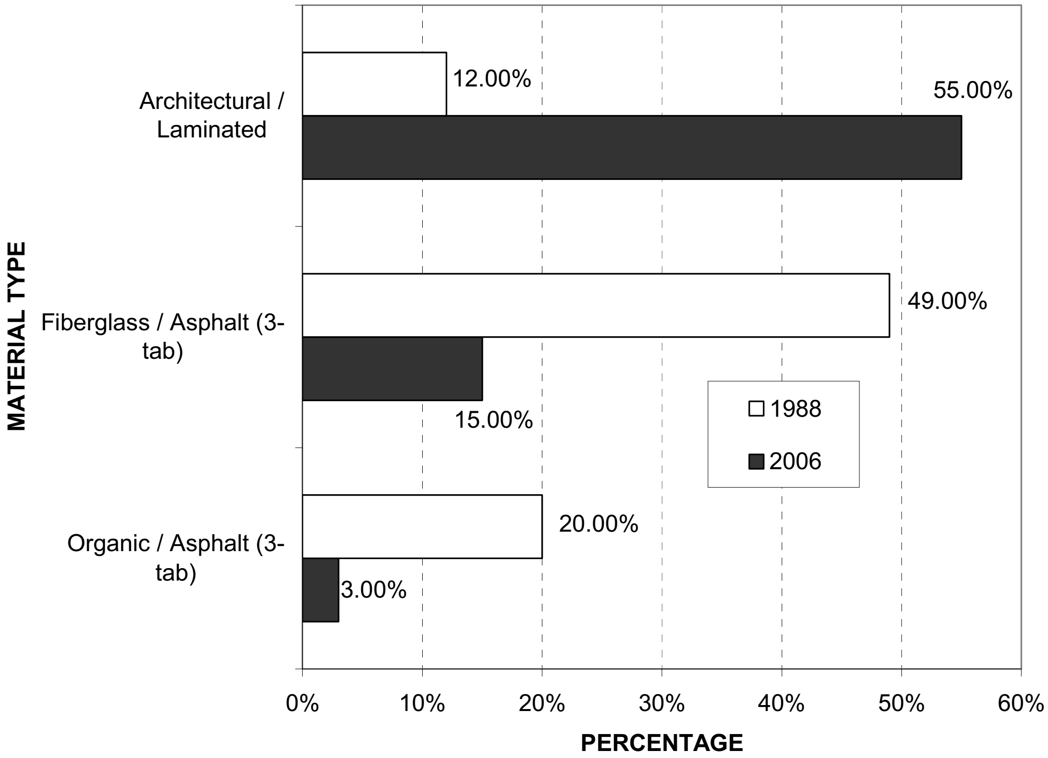

Figure 10.5. Average Roofing Contractor's Volume—Asphalt Composition (1988, 2006) *Source: RSI*

Impact Resistance Test Standards: UL 2218 and FM 4473

Beginning in the early 1990s, the insurance industry recognized hail as a significant cause of loss and attempted to identify roofing products that would mitigate repeated damage being experienced by homeowners in hail-prone states. Working with the Insurance Institute for Property Loss Reduction (IIPLR now IBHS), Underwriters Laboratories, Inc. (UL) developed a laboratory test method that would replicate various impact energies of free falling hailstones. The test standard was initially issued by UL in May of 1996 (rev. January 2002) and is referenced as *UL 2218—Impact Resistance of Prepared Roof Covering Materials*. The goal was to develop a test standard that would provide consumers with performance benchmarks relative to impact resistance and, thus, prompt manufacturers to produce products that would meet or exceed those benchmarks.

The test consists of dropping steel ball bearings ranging in size from 3.175 cm to 5.080 cm (1.25 in to 2 in) from heights ranging from 3.657 m to 6.096 m (12 ft to 20 ft) to impact 0.914 m x 0.914 m (3 ft x 3 ft) test samples at specific damage prone locations that include but are not limited to edges, corners, unsupported areas, overlaps, and joints (Figures 10.6 and 10.7) (UL 2002).

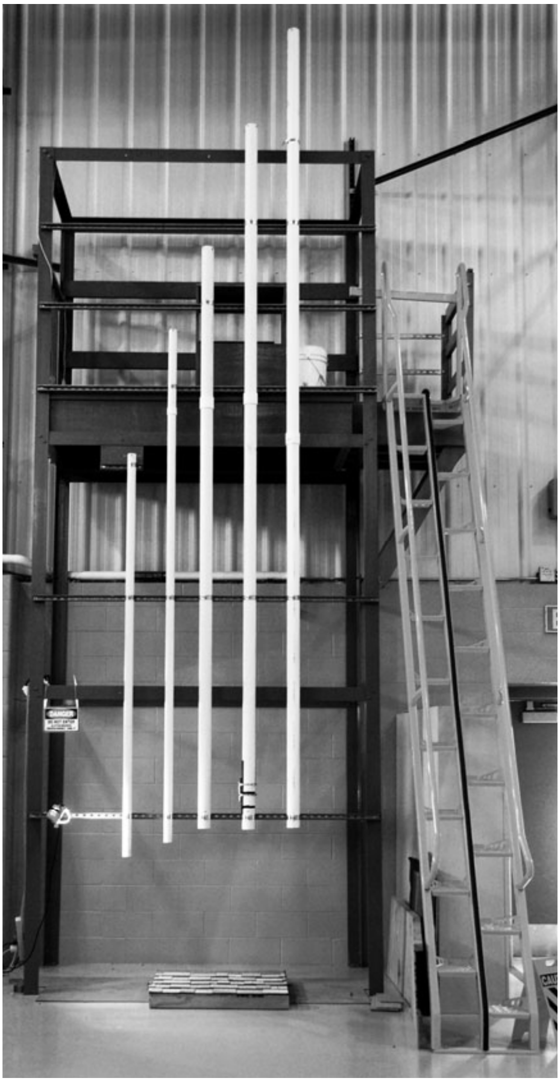

Figure 10.6. UL 2218 Drop Tower

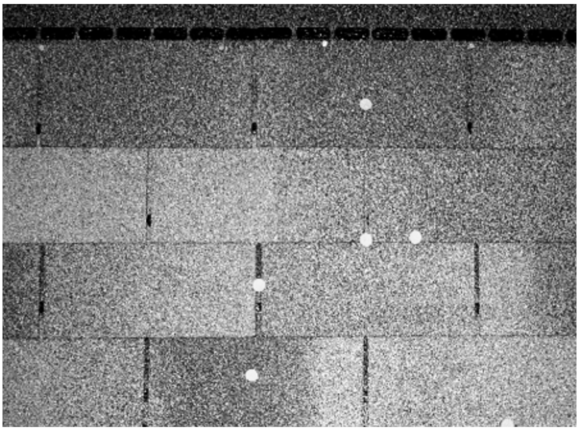

Figure 10.7. UL 2218 Test Sample and Impact Points

Products are then evaluated for damage and ranked by impact classification ranging on a scale from 1 to 4. Impact Classification 4 is currently the best possible rating. Today, tested and rated products are referred to as *Impact Resistant Roof (IRR)* products. The UL 2218 test is only conducted on new products and does not take into consideration material degradation over time due to the natural aging process, a process that includes factors such as exposure to ultraviolet light, heat/cold cycles, and moisture.

To quantify how much actual hail damage could potentially be eliminated or reduced, impact testing using the UL 2218 standard was conducted by State Farm researchers on a selected sample of commercially available roofing products produced by major roofing manufacturers in the United States. The sample consisted of products available in specific regional markets as well as some nationally marketed products. It immediately became apparent during testing that the UL 2218 standard effectively differentiated product performance relevant to impact resistance. The test also provided insight into which products could potentially withstand the most intense impact energies and could, therefore, be expected to perform well in actual hailstorms.

This research indicated no direct correlation between impact resistance performance and product cost, weight, or the time limit specified in the manufacturer's warranty. Of the asphalt composition products initially tested, 56 percent (45) failed to achieve the lowest impact class, Classification 1 rating (Table 10.1). A Classification 1 rating was attained by 28 percent (22) of the products tested, while 16 percent (13) achieved a UL classification 2 or above.

Table 10.1. UL 2218 Impact Test Results by Class (Asphalt Composition Products) (1995-1999)

UL Classification	Missile Diameter cm (in)	Impact Energy J (ft-lbs)	No. of Products	% of Total
No Rating[a]			45	56%
Class 1	3.175 (1.25)	4.55 (3.36)	22	28%
Class 2	3.81 (1.5)	9.76 (7.2)	3	4%
Class 3	4.445 (1.75)	18.20 (13.43)	6	7%
Class 4	5.08 (2)	31.18 (23)	4	5%
Totals			80	100%

[a] Failed to meet UL Classification 1

When the UL 2218 test protocol was initially developed, it was perceived by some to be incapable of accurately predicting the impact performance of rigid materials such as clay and concrete tile due to the density of the steel ball bearings prescribed in the protocol. In an effort to complement the UL 2218 test standard, IBHS, State Farm, the Tile Roofing Institute, and FM Global developed an industry impact standard for rigid roofing materials using ice as an impact medium: Factory Mutual Global—*FM 4473 (July 2005)—Specification Test Standard for Impact Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls* (Figure 10.8) (FM Global 2005).

Figure 10.8. FM 4473 Impact Medium

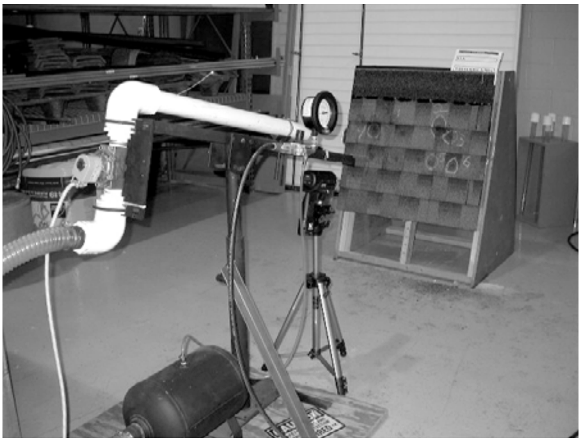

Figure 10.9. FM 4473 Ice Ball Launcher Set-up

Using an ice launcher (Figure 10.9), the FM 4473 test standard provides a method by which rigid material manufacturers can test products and receive an impact rating similar to UL 2218. This standard further encourages the use of materials designed to perform better during hailstorm events, thereby reducing damage.

Damage Reduction: Roofing Premium Credit Programs

Three years after testing began, State Farm implemented a program to encourage mitigation and reduce damage. Policyholders receive a base premium credit (discount) on their insurance premium if they install an impact resistant roof. Credits range from 1 to 30 percent depending on where the home is located. As of June 2007, the program was available in 21 states and one Canadian province. Other insurers also offer similar credit or discount programs for use of IRR products.

Since little can be done to stop hailstorms from occurring, this program has been designed to reduce damage by encouraging the use of impact-resistant products.

Consumers benefit because this program will help keep insurance available and affordable.

Currently the number of IRR discounted policies in force is relatively low in comparison to the overall number of roofs at risk. However, it is expected that as homeowners replace roofs that are damaged by wind/hailstorms occurring during the next decade, there will be a steady growth in the number of IRRs, which should in turn lead to a reduction in damage.

When UL 2218 was first developed (1996), roofing material manufacturers were slow to respond. By 1998 when credit programs were first initiated, only a few manufacturers had chosen to have their products tested and formally listed by UL. In Texas where the hail hazard is substantial, the state decided to require that all insurers participate in the discount program and most types of roofing materials are eligible for the credit. Substantial growth has occurred since the Texas program's inception—from an initial 26 eligible products to now more than 700 for consumers to choose from (Table 10.2). All products are required to be tested by independent laboratories in accordance with the UL test protocol.

Table 10.2. Number of Products Eligible for Premium Credit in Texas (1998 and 2007)

	Feb-98	Jun-07
Material Type (Product Description)	No. of Manufacturers (No. of Products)	No. of Manufacturers (No. of Products)
Metal (Formed Shingles or Panels)	3 (14)	111 (614)
Asphalt Composition (3-tab or Laminate Shingles)	2 (7)	11 (28)
Wood (Shakes or Shingles)	0 (0)	16 (45)
Fiber Cement (Shingles)	1 (1)	0 (0)
Alternative (Recyled Resin, Urethane Foam, Plastic, etc.)	3 (3)	14 (31)
Commercial	1 (1)	4 (5)
Totals	10 (26)	156 (723)

It should be noted that metal roofing manufacturers currently dominate the available IRR product totals. Metal products typically are able to maintain their water shedding ability after a hailstorm even though they may be dented. For these products, some insurers require homeowners to sign a cosmetic damage exclusion waiver prior to receiving the insurance credit.

The fact remains that in 2006, 73 percent of the residential roofing material sold in the United States was asphalt composition (Russo 2006). It is encouraging to note that the majority of the roofing manufacturers producing asphalt composition products are now also producing IRR products.

Case Study: 2003 Dallas/Fort Worth Hailstorm

On April 5, 2003, numerous supercell thunderstorms developed in West Texas and began tracking to the east. Throughout the afternoon and evening hours, storms produced heavy rain, lightning, and tremendous amounts of large hail (some exceeding 4 inches in diameter). Local reports of straight-line wind gusts approaching 113 kilometer per hour (70 mph), and even a few weak (F0) tornadoes were reported. One of these storms affected a swath several kilometers wide and nearly 645 kilometers (400 miles) long, which tracked eastward directly over the northern suburbs of Fort Worth and Dallas. This was one of the most costly storm events ever to hit the state of Texas. It is estimated that the total statewide insurance payments of $885 million dollars, were predominantly due to hail damage. (Smart, J. 2005).

In light of the severe nature of the storm, the Institute for Business and Home Safety (IBHS) embarked on a study of the event. It collected specific underwriting and claims data from three member insurance companies on nearly 320,000 homeowner's policies throughout the northern suburbs of Dallas and Fort Worth. One of the most important conclusions was that homes with impact resistant roof coverings had a lower proportionate reporting of claims. "For impact-resistant asphalt shingle roofs, the decrease in the percentage of homes with claims resulting in insurance payments varied between 40 percent and 60 percent, depending upon the size of hail the roofs were subjected to. For homes with impact-resistant metal roofs, the decrease was between 60 percent and 80 percent." (Smart, J. 2005).

During this storm, it is estimated that State Farm's policyholders avoided about $2.8 million (2003 U.S. dollars) in damage due to the presence of IRR products. At the time the storm occurred, only 1 percent of the insurer's homeowners in the storm's path had impact-resistant roofs. If instead 10 percent of the insureds had installed impact-resistant roofs, it is estimated that almost $22 million (2003 U.S. dollars) in property damage claims could have been prevented (State Farm 2003). If 10 percent *of all homeowners* in the affected area had IRR roofs, it could be estimated that almost $75 million dollars in damage could have been eliminated. This estimate is based on extrapolation of State Farm Lloyd's (Texas affiliate) market share in 2003 (29.57 percent) and the assumption that statewide market share was mirrored throughout the impacted geographic area (TDI 2004).

Summary and Conclusions

Damage from hailstorms severely affects the built environment, especially residential structures and, in particular, the roof coverings of these buildings. The hailstorms that occur east of the Rocky Mountains (with the most frequent and severe storms occurring in the plains states) annually cause millions of dollars in damage. Technological advances in remote detection (Doppler radar) have allowed for a more systematic and unbiased methodology in determining the extent of hail occurrences. This greater understanding of the true frequency of storms, and thus real hail potential, supports the need for more methods and materials designed to resist hail damage.

Studies from hail experts referenced in this paper have quantified damaging hail size and the types of materials typically damaged. Through the examination of Doppler radar records, scientists now know how often hail occurs. When combined with information about the size of hail that produces damage, risk-based maps have been developed that can be used to forewarn those at risk of hail to the hazard that they face. For commercial and residential roofing requirements, model building codes in the United States have typically focused on fire and wind resistance testing. Because hail can be so destructive, attempts continue to be made to make hail risk information available through the various national building codes.

As noted, difficulties arise in analyzing insurance industry hail statistics as hail and wind losses are often coded together in the data. Even so, areas at high risk, either due to high frequency (Texas) or potential for severe (large) hail (Colorado) are experiencing population growth. The increasing number of households translates into more roof area per square kilometer that will be exposed to hail risk. While it may be difficult to precisely quantify the relative contributions of wind damage versus hail damage in the loss records, both types of damage necessitate premature replacement of building envelope materials, which is economically unfair to consumers and unjustified given the availability of impact resistant products.

Since hail damage to buildings, vehicles, and crops is typically covered by insurance, the insurance industry has a vested interest in understanding this hazard. The cost of insurance is reflective of the hazard, which is escalating due to large home (roof) sizes and increasing growth of the metro areas at risk. These wind/hailstorms are of particular concern to the insurance industry when loss event records are compared and examined. In 2005, four of the 20 most costly insurance losses worldwide involved hail (SwissRE 2006). While there is a high potential for damage, there are also very good alternatives available for mitigating the extent of damage—especially to the vulnerable roof covering materials most at risk.

Recognizing the severity of the hail threat, the insurance industry has found a viable solution to mitigate repeated and significant residential hail losses in hail-prone states. Because it is unlikely that hailstorms can be prevented, damage reduction efforts must continue to focus on improving roofing material damage resistance. The primary way this is being accomplished is through the development of test methods designed to differentiate the various roofing products available in the marketplace. As a result, consumers are provided choices in roofing materials that mitigate damage.

In addition to the development of tests that provide product selection criteria for consumers, impact research findings were used to help establish insurance premium discount programs in hail-affected states. The potential benefits should encourage a greater use of risk/location-appropriate roofing materials and result in less or no damage, which also may eliminate the need for roof replacement. The effectiveness of these efforts is being monitored.

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Index