Concrete Building Systems: Disaster Resilient Solutions for Safer Communities

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ABSTRACT

Over the past few decades, there was an exponential increase in human and material losses from disaster events. 2011 was a record-setting year for loss of life and property in virtually every part of the country. 2012 has produced another set of tragic, record-setting convective storms and wildfires. While the green building movement has traditionally focused on the environmental aspects of buildings, communities must now address the need for resilience while rebuilding to meet the challenge of the next natural disaster. This paper presents a four step process for resilient construction including adopting a basic building code, promoting market driven resilience programs, adopting more robust resilience standards and building with more robust materials such as concrete. It provides an overview of concrete building systems that have the mass and hardness to resist high winds and flying debris of tornadoes and the devastating effects of flood, fire and earthquakes.

RESILIENCE IS THE NEW SUSTAINABILITY

At the end of 2011, the National Oceanic and Atmospheric Administration (NOAA) said the U.S. had experienced 14 separate disasters, each with an economic loss of $1 billion or more, surpassing the record set in 2008 (NOAA 2011). 2011 losses amounted to $55 billion in the U.S. Globally, insurers lost at least $108 billion on disasters in 2011. Reinsurer Swiss Re Ltd. said that 2011 was the second-worst year in the industry's history. Only 2005, with Hurricane Katrina and other major storms, were more costly (Swiss Re 2011).

In 2012, there have been 11 natural disasters costing $1 billion or more in damage, making 2012 the second highest year with billion-dollar disasters. Early season tornadoes, the widespread and intense drought that covered at least 60 percent of the contiguous U.S. and Hurricane Sandy are expected to go down in history as the most costly weather-related disasters in U.S. history.

Most of the increased disaster losses cannot be attributed to an increased occurrence of hazards but changes in population migration and wealth. In the last several decades, population in the United States has increased and migrated toward the coasts, concentrating along the earthquake-prone Pacific coast and the hurricane-prone Atlantic and Gulf coasts. Over 60% of the U.S. population lives within 50 miles of one of its coasts (including the Great Lakes) (CRSR 1997). At the same time, wealth and the value of their possessions have increased substantially. The high concentration of people in coastal regions has produced many economic benefits, but the combined effects of booming population growth and economic and technological development are threatening the ecosystems that provide these economic benefits. Moreover, many elements of these aged infrastructures are highly vulnerable to breakdowns that can be triggered by relatively minor events (Masters 2011).

Disasters result not as much from the destructive agent itself but from the way in which communities are (or are not) prepared. Disasters happen when the natural systems are encroached upon by human development. There is no such thing as a natural disaster. The extent of disruption caused by a disaster is greatly influenced by the degree to which society chooses be fortified for the event. It is apparent that there needs to be significant shift in how we address natural disasters, moving away from the traditional focus on response and recovery toward emphasis on resiliency, that is, preventive actions to reduce the effects of a natural hazard.

Resilience can be understood as the capacity to anticipate and minimize potential destructive forces through adaptation or resistance. Basically addressing changes in the environment requires actions to mitigate their negative effects. If we identify resiliency, not solely as a state of preparedness for disaster, but as a desired characteristic of a sustainable society, one more in control of its energy and food production, access to water supplies, as well as being one that enables local social capital, we can begin to see the relationship. The term ‘sustainability’ usually describes some aspect of maintaining our resources from the environment to the quality of life, over time. It can also refer to the ability to tolerate—and overcome—degradation of natural environmental services, diminished productivity and reduced quality of life inflicted by man’s relationship to the planet and each other.

Critical infrastructures and other essential services have enabled societies to thrive and grow and become increasingly interconnected and interdependent from the local to global levels. As a society, we have placed a great deal of emphasis on recycling rates and carbon footprints. We are surprisingly willing to invest considerable amount of upfront capital for a LEED (Leadership in Energy and Environmental Design) Platinum certified building to achieve a mere 14% energy efficiency, yet be completely satisfied if the structure meets only the code minimum requirements for seismic or wind load.

The California Green Building Code, the ASHRAE 189.1 Standard, and the ICC700 (National Green Building Standard) all cite life-cycle assessment (LCA) as a means to promote sustainable building practices. The latest version of LEED rating system developed by the U.S. Green Building Council (USGBC) introduced special emphasis on regionalization and LCA criteria, but does not recognize disaster resilience as one of its standard criteria. The building service life plan (BSLP) elective by the International Green Construction Code (IGCC) gives credit to proposed projects designed to have a 100 year or 200 year life span as approved by the jurisdictions.

This is good start as building service life is rarely considered but is critical to any analysis of long-term sustainability. Balancing long term development plans with the ability to adapt to the needs of a rapidly evolving society is vital to the ultimate success of a building life plan. But for green building standards to truly address sustainable construction, they will have to address the concept of disaster resilience.

For a building to be truly sustainable it should be resilient. It should consider potential for future use and re-use and have a long service life with low maintenance costs. In addition, a sustainable building should be designed to sustain minimal damage due to natural disasters such as hurricanes, tornadoes, earthquakes, flooding and fire. Otherwise, the environmental, economic and societal burden of our built environment could be overwhelming. A building that requires frequent repair and maintenance or complete replacement after disasters would result in unnecessary cost, from both private and public sources, and environmental burdens including the energy, waste and emissions due to disposal, repair and replacement.

It doesn't make sense to design a modern building, commercial or residential, to meet LEED or other green building requirements that could be easily destroyed as a result of a hurricane, earthquake or other force of nature. That would mean that all of the green technology and strategies used in the building would go to the landfill. What is the point of installing low flush toilets in a home to conserve water if it ends up in a landfill after a tornado blows through?

FOUR STEPS TO DISASTER RESILIENCE

There are essentially two ways to approach mitigation. There are voluntary programs where communities or building owners voluntarily reduce their risk of natural disaster through enhancements in structures, warning systems and education. The second approach is to install mandatory building code requirements such that communities and building owners are obligated to design buildings and infrastructure to be more disaster resilient. We propose the following four steps, combining both voluntary and mandatory mitigation strategies, to achieving disaster resilience:

- Adopt a Building Code
- Encourage Voluntary "Code Plus" Construction
- Adopt High Performance Building Standards
- Build with Robust Materials

1. Adopt a building code. About 200 years ago, in 1811 and 1812, there were earthquakes that were so powerful in the area 50 miles north of Little Rock, AR, that seismologists still talk about it today. All of the quakes were estimated to have been magnitude 7.0 or greater. It is said that those earthquakes opened deep fissures in the ground, caused the Mississippi River to run backwards and that they were felt as far away as Boston. The earthquakes along the New Madrid Seismic Zone rank as some of the largest in the United States since its settlement by Europeans. The area of strong shaking associated with these shocks were 10 times as large as that of the legendary 1906 San Francisco earthquake. Despite the significant risk, many communities living near the New Madrid fault have not enacted significant earthquake preparedness policies such as the adoption of building codes with more stringent seismic requirements.

Building codes are effective for reducing disaster risk. A building code sets standards that guide the construction of new buildings and, in some cases, the rehabilitation of existing structures. Currently, building codes set minimum construction standards for *life safety*. Maintaining the functionality of structures is important for high-risk areas, but more importantly may be critical for certain groups that are more vulnerable to natural hazards, those who do not have a choice on where they live and work.

To date, among the eight States in the New Madrid Seismic Zone, five (Arkansas, Indiana, Kentucky, Missouri and Alabama) have statewide building codes for residential construction as minimum requirements, but three (Illinois, Mississippi, Tennessee) do not and they pass the responsibility to the local jurisdictions to adopt the codes themselves. Although earthquakes are high-consequence events, seismic mitigation in Mid-America generate little public interest because earthquakes in this region are low frequency.

If we are to take people's vulnerability seriously, we must deploy—and insist on—much greater technical expertise in resilient code adoption. The design community can provide some of the expertise, but their skills are not being effectively considered on the planning and policy level. The key, missing element is awareness among practitioners, the development community, and policy makers.

2. Encourage Voluntary "Code Plus" Construction. One way to encourage communities to develop fortified structures, enforce building codes and land-use management measures is to provide insurance premium reductions to all policy-holders in the area based on the stringency of land-use regulations, building code standards, and inspection. The more effective a community program is in reducing future disaster losses, the greater the insurance premium reduction. The Federal Insurance Administration created such a community rating system in 1990 as a way to recognize and encourage community flood plain management activities. This model could be applied to other hazards as well.

Another approach, the FORTIFIED for Safer Living and Safer Business program of the Insurance Institute for Business and Home Safety (IBHS) are voluntary programs aimed at incorporating building techniques into construction to provide an optimum level of protection against a variety of natural hazards. IBHS is a not-for-profit applied research and communications organization supported by the insurance industry. Their focus is to reduce or eliminate residential and commercial property losses due to wind, water, fire, hail, earthquake, ice and snow (IBHS 2012). The programs also address other business continuity issues such as such as interior fire, burglary, lightning protection and electrical surge.

IBHS promotes the need for strong, well-enforced building codes but also realizes that building codes offer minimum life safety standards and often don't have the necessary provisions to provide disaster resilience. For that reason, IBHS developed it FORTIFIED programs that provide specific design criteria and the necessary construction and inspection oversight to ensure "code plus" structures that are truly disaster resilient.

Over 250 homes have been designated as FORTIFIED since 2001. The program was battle tested by Hurricane Ike on the Bolivar Peninsula in Texas in September 2008. Ten of 13 FORTIFIED homes survived a direct hit from Hurricane Ike, including a 20 ft. storm surge. These FORITIFED homes were the only structures left standing for miles around, precisely because they were specifically designed and built to withstand extreme wind and water damage. The three FORTIFIED homes that did not survive were collapsed when other homes in the area slammed into them.

3. Adopt High Performance Building Standards. Adopting high performance building standards involve having local, state and federal governments adopt stricter standards for construction of buildings and infrastructure with the objective of reducing losses from natural hazards. The two primary model building codes in the U.S. are the International Building Code (IBC) and the International Residential Code (IRC). Depending on location, some states and municipalities adopt the model codes for their jurisdictions.

The Portland Cement Association recently developed *High Performance Building Requirements for Sustainability* that go beyond the basic building code and enhance the key concepts of durability and disaster resilience. Essentially these provisions state that for a building to be considered green, it must not only conserve energy and water, use materials efficiently, and have a high-quality indoor environment but it must also reasonably withstand natural disasters. In other words, a sustainable building must be long-lasting and durable (PCA 2012).

In addition, high performance buildings should not be a burden on their communities. They should be sufficiently resilient to disasters to ensure continuous operation and not place excessive demand on community resources such as emergency responders including fire, police and hospitals. Communities with disaster resilient buildings are more likely to be able to continuously operate hospitals, schools, and businesses after a disaster. Stronger homes and buildings mean people will have places to live and work after a disaster. Less disruption for a community means robust commerce and consistent tax revenue.

National associations such as the National Ready Mixed Concrete Association (NRMCA) and the Portland Cement Association (PCA) continue to work at the national level to make changes to the model codes to incorporate these high performance standards. This process is difficult and could take years. However, local jurisdictions could use the standards in whole or in part to strengthen building codes to address specific hazards for their community.

4. Build with Robust Materials. The final step towards disaster resilience is to build with robust building materials. Some of the qualities of robust building materials include versatility, strength, wind and water resistance, seismic resistance, fire resistance, energy efficiency and durability. Concrete building systems are especially suited to provide resistance to natural hazards. Concrete has the necessary hardness and mass to resist the high winds and flying debris of tornadoes and hurricanes. Concrete is fire resistant and non-flammable, which means it can contain fires and will not contribute to the spreading of fire. Reinforced concrete framing systems can be designed to resist the most severe earthquakes without collapse. Concrete doesn't rot or rust even if it is subject to flooding.

CASE STUDIES

There are many examples of structures built with heavy building materials such as concrete surviving major disasters. When Hurricane Katrina slammed into the coastal counties of Mississippi with sustained winds of 125 mph and a storm surge that reached 28 feet, the only house to survive along the beachfront of Pass Christian, MS, was the Sundberg home. Scott and Caroline Sundberg were 85% complete building their dream home along the Mississippi coast when the Hurricane hit. When the winds died down and the water retreated, the Sundberg home had survived the storm. All other homes on the beachfront were completely destroyed. They built their home using insulating concrete forms (ICFs) for the walls and cast-in-place concrete frame construction for the lower level, floors and roof precisely for this reason—to survive the devastating effects of a hurricane.

Figure 1. The Sundberg's concrete home survived the devastating effects of high winds and storm surge of Hurricane Katrina (FEMA/John Fleck).

Wild fires consume an average of nearly 7,000 square miles annually since 1960. In the last decade, that number has increased to over 10,000 square miles (NIFC 2012). A 1993 wildfire in Laguna Beach, CA, consumed 17,000 acres and destroyed 366 homes in a single day. Figure 4 shows the lone survivor which remained protected by an envelope of non-combustible stucco wall cladding and concrete roof tiles. Detailing such as stucco cladding on walls, eaves and trim, as well as Class A concrete tile roof prevented combustion of the exterior amidst the firestorm that swept through the community.

Figure 2. Stucco cladding and eaves along with concrete roof tile helped protect this home during a 1993 wildfire in Laguna Beach, CA (AP Photo/Douglas C. Pizac).

The EF-4 tornado that roared through Tuscaloosa, AL, on April 27, 2011, leveled block after block in the Forest Lake neighborhood. The only thing left standing was a closet at the Blakeney residence on 16th Street East. The closet was built as a safe room using 8-inch reinforced concrete masonry to withstand high winds and flying debris caused by tornadoes (Jones 2011). Small windowless rooms such as a walk in closet are ideal locations for a safe room in a home.

Figure 3. William Blakeney helped build this safe room inside his grandparents' home in Tuscaloosa, AL, before a tornado hit destroying the home and most homes in the neighborhood (The Tuscaloosa News/Michelle Lepianka Carter).

Concrete proves to be the most widely used method for constructing safe rooms**.** FEMA has funded testing programs, primarily at Texas Tech University to determine the proper design to resist windborne debris on walls, doors, and roofs. The Texas Tech research included firing a test missile – a 15- pound, 12-foot-long 2x4– at combinations of wall, ceiling, and door construction materials. The missile was fired at speeds of 67 mph and 100 mph to simulate the speeds of similar-sized debris driven vertically downward and horizontally, respectively, by 250 mph storm winds. According to the research, concrete systems including cast-in-place concrete, insulating concrete forming systems, precast concrete and concrete masonry pass the test.

ADDITIONAL COST OF FORTIFIED CONSTRUCTION

Building to a disaster resilience standard does cost more but typically result in cost savings over the long run. One report conducted by Blue Sky Foundation of North Carolina found that the additional cost of building a home to the FORTIFIED for Safer Living standard cost an additional $3,936 or about 5% more an a home with a retail value of $80,000. Amortized at 6% simple interest over a 30 year mortgage, the additional monthly cost would be about $24 per month. According to the report, this additional cost is easily offset by likely repairs of the home after the 5-10 hurricanes anticipated over the mortgage period (BSE 2005).

In another example, IBHS reported that a 3-bedroom, 2-bath 1,132 square foot home built to the FORTIFIED standards in Baldwin County, Alabama, only cost $1,000 to $1,500 more than a home built to the standard code (IBHS 2012). Often, the additional cost is offset by lower insurance costs. For example, Flora and Anita Cannon's Spanish Fort, AL, house needed a new roof so they decided to retrofit their home to the FORTIFIED standard for existing buildings. The Cannons paid nearly $3,500 per year for insurance before the upgrades but the policy was reduced to less than $1,800 once the house is retrofitted to the FORTIFIED hurricane standards (Jumper 2011).

BENEFITS OF NATURAL HAZARD MITIGATION

Natural hazard mitigation is a resilience strategy that saves lives and money. In 2005, the Multihazard Mitigation Council (MMC) of the National Institute of Building Sciences conducted an independent study for Congress funded by the Federal Emergency Management Agency (FEMA) to study the effectiveness of disaster mitigation. The report, *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities*, quantified the future savings, in terms of losses avoided, from government grant hazard mitigation activities from 1993 to 2003 (NIBS 2005). The benefits of mitigation were defined as the potential losses to society that were avoided as a result of investment in mitigation. Those benefits include:

- Reduction in property damage
- Reduction in business disruption
- Reduction in nonmarket damage (environmental damage to wetlands, parks, wildlife and historic structures)

- Reduction in deaths, injuries and homelessness
- Reduction in cost of emergency response (ambulance and fire service)

The study indicates that the natural hazard mitigation grant programs funded by FEMA were cost effective and did in fact reduce future losses from earthquakes, wind and floods. The mitigation programs resulted in significant net benefit to society and potential savings to the federal treasury in terms of future increased tax revenue and reduced hazard related expenditures. The FEMA grant programs cost the federal government $3.5 billion from 1993 to 2003 but yielded a societal benefit of $14 billion. That is, for every dollar spent on mitigation saved four dollars in avoided future losses.

CONCLUSION

Resilience planning offers communities an opportunity to play a major role in determining the essential services and infrastructure needs that underpin their economic vitality, the health and safety of its citizens, and support sustainability. Voluntary methods such as IBHS's FORTIFIED programs are valuable, but the most effective method would be to change model building codes at the national level. By participating in code development so that all model codes include hazard mitigation for water, energy, conservation, and land use, a community makes the conscious choice to invest in their own future regardless of socioeconomic status.

The building codes are not a panacea for all problems. Nevertheless, to subject our vulnerable population to the all too often, shortsighted political or economic decisions that trump safety considerations is unconscionable when the technology and economic returns of disaster resilience are well understood.

Disaster mitigation works and is cost effective. Spending time and money up front to reduce the likelihood of loss during a natural disaster can bring significant benefits to building owners and communities including lower insurance costs, higher property values, security to residents, maintaining a consistent tax base, and minimizing the cost of disaster response and recovery.

In the end, no community can ever be completely safe from all hazards. Generally, it would be uneconomical to design commercial or residential buildings to survive a direct blow from a tornado with 300 mph wind speeds or magnitude 9.0 earthquake. But resilience promotes greater emphasis on what communities can do for themselves before a disaster hits, and how to strengthen their local capacities, rather than be dependent on our ineffectual governmental agencies and aging centralized infrastructure. Disasters are inevitable, but their consequences need not be.

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