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THE 21ST CENTURY GOAL FOR SEISMIC SAFETY RESILIENT CITIES

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ABSTRACT

The new century has brought the new perspective that goals for natural hazard reduction need to shift from safety to resilience. What constitutes life safety began with the goal that occupants have a reasonable chance of being safe inside a building during the earthquake and are able to exit on their own afterwards. Resilience requires a complete set of transparent performance goals that declare what is needed from both the lifeline systems and the buildings to facilitate recovery. The federal government should take the lead in establishing goals needed for recovery along with incentives to adopt and implement them. The federal government needs to set performance standards that can be embedded in the design codes, provide financial incentives to stimulate mitigation that benefits the nation, and continue to support research that delivers new technologies that minimize the cost of mitigation, response and recovery. The City and County of San Francisco has launched a comprehensive recovery planning initiative comprised of 75 different projects aimed at improving the City's ability to recover. The overarching benefit of the shift from safety to resilience is the ability of communities to take the hit of a natural disaster in stride and recover to a new though recognizable normal without loss of life, their economies, jobs, or cultural heritage.

INTRODUCTION

Design and construction professionals have been working to understand and mitigate the effects of earthquakes for centuries. While the historical record in the beginning is vague, there is evidence to suggest that local construction techniques changed with each major earthquake and it is reasonable to expect that the goal was always to protect life and property. It appears that early on, designers understood that building strength, configuration, and the interconnection of elements were keys to improved performance. In the United States, the 1906 San Francisco earthquake and fire initiated an understanding in California that has never stopped evolving. The Seismological Society of America was born out of that event and has never stopped working to understand and characterize the shaking to be expected. Engineers, at the same time, never stopped working to understand and refine their designs to be earthquake-resistant. The goal for seismic design focused on limiting damage in moderate earthquakes and preserving life in major events (Geschwind 2001).

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Starting in the mid-20th century, building officials with the help of engineers started to legislate the style and extent of seismic design that would be required for ultimate safety. Lifeline system owners generally followed suit. By the mid 1980s, most agree that the resulting guidelines codes and standards defined what was needed for earthquake-safe buildings and systems. It was a matter of proper design, detailing, and construction. As new projects were built, the safety of communities began to improve, though they remained plagued by the vast majority of existing buildings, built prior to the modern codes. While some of those buildings are actually quite good due to the wisdom of their design and constructors, most are not and a small subset are outright dangerous and capable of causing a large number of casualties. Over the years, most attempts to require rehabilitation of these existing buildings and systems to bring them to a level of safety comparable to the new standards have been blocked. It is expensive, not everyone is concerned about the potential damage, and more often than not, most people do not know the level of damage that is expected to occur.

The 1994 Northridge Earthquake brought home the reality and consequence of earthquake damage. Engineers were delighted with the life safe performance of their buildings, especially the unreinforced masonry buildings that had recently undergone mandatory rehabilitation. The public, the government, and especially the insurance companies were all startled by the cost of the damage and the disruption to people and business, especially small local businesses. The call for better performance led to the formalization of performance based seismic engineering that has yielded new standards for evaluation, rehabilitation and new building design (SEAOC 1995).

Unfortunately, the traditional silos that separate designers and confuse the public were not immediately broken down and the resulting efforts for implementing performance based seismic engineering stalled. New buildings continued to be designed for prescriptive requirements without clear definition about was being accomplished (ASCE 1995). Existing buildings continued to be evaluated and rated for a wide variety of performance goals with no direct relationship to those being used for new buildings (ASCE 2002, 2006). Lifeline systems, the very heartbeat of a community's economy, continued to be designed and rehabilitated by their public and private providers and without consistent understanding of their independencies on other systems or the consequences of their systems failure on the pace of the recovery.

Fortunately, the new century has brought a new perspective. Driven by the experiences in 9/11, the Katrina floods, and now the Haiti Earthquake, many earthquake professionals now realize the goals for natural hazard reduction need to shift from safety to resilience. Communities need to be able to take the "punch" of an event and depend on their own preparedness and impromptu response of those affected to recover. Their preparedness needs to focuses on saving people, their neighborhoods, their cultural heritage, and the local economy. It requires a clear understanding of the social and physical impacts of the disasters that may occur and find its way through the various levels of risk tolerance, experience with previous disasters, need for simplicity, cost impacts, and a wide variety of political barriers and compromises.

START FRESH WITH GOALS RELATED TO RECOVERY

Healthy cities continuously grow by driving economic development while protecting their cultural heritage. Success, in part, depends on a healthy-built environment that is rooted in contemporary urban planning, sustainability and disaster resilience. Disaster resilience requires a response and recovery plan that involves the response capabilities of both the social and physical infrastructure. The plan is about people, their intuitive response capability, governance, finance, and the condition of the infrastructure. The infrastructure needs to provide a place to govern after a disaster, and power, water, and communication networks must begin operating quickly. People need to be able to return almost immediately to their homes, travel to where they need to be, and resume a fairly normal living routine within a few weeks. Communities can then return to a "new" normal, which occurs within a few years after the event (ACEHR 2010).

Engineering professionals are rarely clear about the level of damage that can occur to their buildings and lifeline systems when the natural hazards they are designing for occur. While this is a comfortable position to take because of the concern about liability, it has led to a significant misconception on the part of the public and the emergency response planners who believe that the built environment is generally "damage proof" and will be available for immediate reuse. In reality, most buildings and lifelines have been designed to protect their occupants from harm with inconsistent regard given to reusability. Enhanced standards for new construction and mandatory rehabilitation of the selected elements of existing construction are needed to meet the new resilience goals.

Defining disaster resilience and setting resilience goals is a contemporary issue that has generated a wide range of definitions and expectations. Some define it qualitatively with goals for response and recovery. Others have developed an analytical measurement that scores abilities, declares when advancement is needed, and allows overall progress to be tracked. Some have suggested that large, modern urban cities are already sufficiently resilient because of their considerable assets, small impact ratios, and extensive and available government support. However, the City and County of San Francisco has not taken that position and in fact, has launched a comprehensive recovery planning initiative. Comprised of 75 different projects aimed at improving the City's ability to recover, the San Francisco Citywide Post-Disaster Resilience and Recovery Initiative is setting a new pace for achieving resilience (Chakos 2008).

San Francisco Planning and Urban Research Association's (SPUR at www.spur.org), working in collaboration with the City of San Francisco, is addressing the issue within their Disaster Planning Program. As a public policy think tank, SPUR recommends policies to the City and County of San Francisco on a wide range of topics. Their Disaster Planning Program is focused in three areas: mitigation, response, and recovery. The SPUR program started during the commemoration of the 100th anniversary of the 1906 Earthquake and Fire. To date, SPUR has drafted an overarching paper defining a Resilient San Francisco in terms of goals for the condition of the cities built environment and a series of recommendations related to the first steps needed to achieve goals related to new and existing buildings and lifelines.

The SPUR goals for resilience are defined in the context of disaster planning by defining what the city needs from its buildings and lifelines to support the three phases of response, rescue, recovery and rebuilding. In the first phase, the weeklong response and rescue period, only the emergency response centers are needed. The second phase of recovery focuses on restoring the neighborhoods within 30 to 60 days so that the workforce can be reestablished, their communities restored, and people are able to return to a normal lifestyle and back to work. Special consideration must be given to the needs of the economically and physically challenged populations. The third phase of recovery covers the repair and reconstruction of the affected area (SPUR 2009).

DEFINE EXPECTED AND EXTREME EARTHQUAKES

Earthquakes arrive in all sizes and shapes. The intensity of shaking at a particular location depends on the local site conditions, the distance location of the epicenter, the magnitude, and the geologic conditions along the path. Early definitions of the largest earthquake that could affect a site were defined in terms of the strength of the buildings since there were few instrumental measurements available or metrics for describing ground motion in engineering terms. In the early 70s, hazard assessment advanced to the point that the largest expected earthquake, the maximum credible earthquake, was defined based on an extrapolation of the earthquakes that were known to have occurred. In recent decades, that definition has given way to probabilistic estimates of earthquake of various sizes and probabilities of occurrence. For purposes of design today, ground motion with a 10% probability of exceedence in 50 years (the 10/50 ground motions) and ground motions with a 2% probability of exceedence in 50 years (the 2/50 ground motions) are the basis. These ground motions are also referred to as having a 500 year return period and a 2500 year return period, respectively. The 10/50 ground motions represent the traditional design level used in the western United States and the 2/50 ground motions, referred to as the maximum considered earthquake, have become the basis for new design.

While probabilistic estimates of ground motion are rational, scientifically defendable, and easily used for design, they are rarely understood by owners and policy makers. Earthquakes are always reported in the public media in terms of a Richter Magnitude. Scenario earthquakes that are used for planning purposes are defined in terms of an expected magnitude because they are easily understood. Using a process of deagregation, the USGS has provided a link between the probabilistic ground motions and the scenario earthquakes. It allows a specific earthquake to be identified as the most likely source of the probabilistic ground motion being considered. In 2003, San Francisco defined four scenario earthquakes for their Community Action Plan for Seismic Safety.

Setting resilience goals requires the combination of a defined level of shaking and a transparent performance goal. To be effective and understood, today's probabilistic definitions need to be translated into equivalent scenario events for effective public policy decision making. For that purpose, SPUR defined three scenario events for San Francisco that included an "expected" earthquake – one that could reasonably be expected to occur during the useful life of the structure or system - along with extreme and routine events. The expected earthquake is defined for use in design and evaluation. The extreme earthquake - the largest earthquake that could reasonably be expected to occur on a nearby fault - is intended to be used as the basis for response planning. The routine earthquake – the event that will likely occur routinely during the life of a building – is intended to verify the service level performance of buildings. That is the level of earthquake a building or system can endure without damage or interruption in its operational ability.

For buildings in San Francisco, SPUR has defined the following:

Routine	Magnitude 5.5, 70% probability of exceedance in 50 years
Expected	Magnitude 7.2, 10% probability of exceedance in 50 years
Extreme	Magnitude 7.9, 2% probability of exceedance in 50 years

For lifeline systems such as major bridges, levees, or utility systems, the useful life of the systems is much longer. The expected earthquake for lifelines should represent a ground motion with a much lower probability than defined for buildings, perhaps even as high as the extreme event.

TRANSPARENT INFRASTRUCTURE GOALS

Early efforts to mitigate the impact of an earthquake on buildings and systems appear to have been based on a goal of eliminating damage and disruption. As those efforts became standard provisions within building codes, the goals for buildings transitioned to a life safety focus where they remain today. This is consistent with the building official's responsibility to protect life. However, specific building code style requirements were never set for lifeline systems.

While not specifically stated, the definition of what constitutes life safety began with the goal that occupants have a reasonable chance of being safe inside a building during the earthquake and are able to exit on their own afterwards. In the Western United States, this life safety goal has quietly expanded to require a higher level of safety and occupancy for schools, high occupancy buildings, facilities containing hazardous materials and further expanded to require hospitals and other emergency operations facilities to remain operational, all in the name of public safety.

The current move from this safety focus to resilience needs to be supported by a complete set of transparent performance goals that declare what is needed from both the lifeline systems and the buildings to facilitate recovery. This does not imply that all facilities and systems need to be designed or upgraded to a level that would make them damage-proof and fully operational after an extreme event. Rather, the intent is to identify what elements of the built environment are needed for effective response and rapid recovery. The traditional definitions of design requirements in terms of use, occupancy, material and structural system need to be expanded to recognize when they are needed in the recovery process. Buildings and systems need to designed and constructed so they are available, after repaired, when needed.

SPUR chose to define performance goals in terms of the following three response and recovery phases, five performance categories for buildings, three performance categories for lifeline systems, and a matrix format as the metric for defining and tracking the state of resilience:

Response and Recovery Phases

Phase	Time Frame	Condition of the built environment
1	*1 to 7 days*	*Initial Response and staging for reconstruction*
	Immediate:	Mayor proclaims a local emergency and opens the Emergency Operations Center. Hospitals, police stations, fire stations, and City Department Operations Centers are operational.
	Within 4 hours:	People who leave or return to the city in order to get home are able to do so.
	Within 24 hours	Emergency response workers are able to activate and their operations are fully mobilized. Hotels designated to house emergency response workers are safe and usable shelters are open. All occupied households are inspected by their occupants and less than 5 percent of all dwelling units are found unsafe to be occupied. Residents will shelter in place[1] in superficially damaged buildings even if utility services are not functioning.
	Within 72 hours	Ninety percent of the utility systems (power, water. waste water, and communication systems) are operational and serving the facilities supporting emergency operations and neighborhoods. Ninety percent of the major transportation systems routes, including Bay crossings and airports, are open at least for emergency response. The focus of the initial recovery and reconstruction efforts will be focused on repairing residences, schools and medical provider offices to a usable condition and providing the utilities they need to function. Essential City services are fully restored.
2.	*30 to 60 days*	*Housing restored – ongoing social needs met*
	Within 30 days	All utility systems and transportation routes serving neighborhoods are restored to 95 percent of pre-event service levels, public transportation is running at 90 percent capacity, public schools are open and in session. Ninety percent of the neighborhood businesses are open and serving the workforce.
	Within 60 days	Airports are open for general use, public transportation is running at 95 percent capacity, minor transportation routes are repaired and reopened.

[1] Shelter in place is used by emergency response professionals to mean the place in a building where people can seek safety during a life threatening incident. SPUR uses "shelter in place" to mean that a building is disaster resilient enough for people to safely remain in their home during both the earthquake itself and subsequent needed repairs, even though the public utility systems may not be working.

3	*Several Years*	*Long Term Reconstruction*
	Within 4 months	Temporary shelters are closed. All displaced households have returned home or have permanently relocated. 95 percent of the community retail services are reopened. 50 percent of the non-workforce support businesses are reopened.
	Within 3 years	All business operations, including all City services not related to emergency response or reconstruction, are restored to pre-earthquake levels.

Performance Categories for Buildings

SPUR uses the following terms in developing new building design standards and mitigation programs needed to achieve San Francisco's resilience objectives. The levels of performance they describe are to be paired with the effects of the expected earthquake.

Category A: *Safe and Operational*. This describes the performance now expected of new essential facilities, such as hospitals and emergency operations centers. Buildings will experience only very minor damage and have energy, water, wastewater, and telecommunications systems to back-up any disruption to the normal utility services.

Category B: *Safe and usable during repair*. This describes the performance needed for buildings that will be used to shelter in place and for some emergency operations. Buildings will experience damage and disruption to their utility services, but no significant damage to the structural system. They may be occupied without restriction and are expected to receive a green tag[2] after the "expected" earthquake.

Category C: *Safe and usable after repair.* This describes the current expectation for new, non-essential buildings. Buildings may experience significant structural damage that will require repairs prior to resuming unrestricted occupancy and therefore are expected to receive a yellow tag[3] after the "expected" earthquake. Time required for repair will likely vary from four months to three years or more.

Category D: *Safe but not repairable.* This level of performance represents the low end of acceptability for new, non-essential buildings, and is often used as a performance goal for existing buildings undergoing rehabilitation. Buildings may experience extensive structural damage and may be near collapse. Even if repair is technically feasible, it might not be financially justifiable. Many buildings performing at this level are expected to receive a red tag[4] after the "expected" earthquake.

Category E: *Unsafe: Partial or complete collapse.* Damage that will likely lead to significant casualties in the event of an "expected" earthquake. These are

[2] Building inspected and deemed safe for occupancy.
[3] Building inspected and found to be damaged enough to warrant restricted access.
[4] Building inspected and found to be unsafe to occupy.

the "killer" buildings that need to be addressed most urgently by new mitigation policies.

Performance Categories for Lifelines

In addition, SPUR defines the expected performance of all utility and transportation systems, or portions of systems, serving the City in terms of the days required to restore service to 90 percent, 95 percent and 100 percent of the defined customer base.

Category I Resume 100 percent of service levels within four hours

Critical response facilities - including emergency housing centers – need to be supported by utility and transportation systems critical to their success. This level of performance assures that these systems will be available within four hours of the disaster. It requires a combination of well-built buildings and systems, provisions for making immediate repairs as needed, and redundancy within the networks that allows troubled spots to be isolated.

Category II Resume 90 percent service within 72 hours, 95 percent within 30 days, 100 percent within four months

Housing and residential neighborhoods require that utility and transportation systems are restored quickly so that these areas can return to livable conditions. There is time to make repairs to lightly damaged buildings and replace isolated portions of the networks or create alternate paths for bridging around the damage. There is time for parts and materials needed for repairs to be imported into damaged areas. These systems need to have a higher level of resilience and redundancy than the systems that support the rest of the City.

Category III Resume 90 percent of service within 72 hours, 95 percent within 30 days, 100 percent within three years

The balance of the city needs to have its systems restored as buildings are repaired and returned to operation. There is time to repair and replace older vulnerable systems with new. Temporary systems can be installed as needed. Most existing lifeline systems will qualify for Category III performance.

SPUR distilled these goals into the resilience matrix, shown in Figure 1, which indicates both the goals and the estimated current condition of the city's infrastructure.

Figure 1

TARGET STATES OF RECOVERY FOR SAN FRANCISCO'S BUILDING AND INFRASTRUCTURE

INFRASTRUCTURE CLUSTER FACILITIES	Event Occurs	Phase 1 Hours			Phase 2 Days		Phase 3 Months		
		4	24	72	30	60	4	36	36+
CRITICAL RESPONSE FACILITIES AND SUPPORT SYSTEMS									
Hospitals								X	
Police and fire stations			X						
Emergency operations center	X								
Related utilities						X			
Roads and ports for emergency				X					
CalTrain for emergency traffic					X				
Airport for emergency traffic				X					
EMERGENCY HOUSING AND SUPPORT SYSTEMS									
95% residence shelter-in-place								X	
Emergency Responder Housing				X					
Public shelters							X		
90% Related Utilities								X	
90% roads, port facilities, and public transit							X		
90% Muni and BART Capacity						X			
HOUSING AND NEIGHBORHOOD INFRASTRUCTURE									
Essential city service facilities							X		
Schools							X		
Medical provider offices								X	
90% neighborhood retail services									X
95% of all utilities								X	
90% roads and highways						X			
90% transit						X			
90% railroads							X		
Airport for commercial traffic					X				
95% transit							X		
COMMUNITY RECOVERY									
All residences repaired, replaced or relocated									X
95% neighborhood retail businesses open								X	
50% offices and workplaces open									X
Non-emergency city service facilities									
All businesses open									X
100% utilities									X
100% highway and roads									X
100% transit									X

Source: *SPUR Urbanist, February 2009*

The "x's" in the chart to the right indicate SPUR's best educated guesses about current standards for recovery times. The shaded areas represent the goals — targets based on clearly stated performance measures (see next page) — for recovery times for the city's buildings and lifelines. The gaps between "x's" and shaded boxes represent how far we are from meeting resiliency targets.

TARGET STATES OF RECOVERY

Performance Measure	Description of usability after expected event: BUILDINGS	LIFELINES
Category A (lightest shade)	Category A: Safe and operational	
Category B	Category B: Safe and usable during repairs	100% restored in 4 hours
Category C	Category C: Safe and usable after moderate repairs	100% restored in 4 months
Category D (darkest shade)	Category D: Safe and usable after major repairs	100% restored in 3 years
X	Expected current status	

GETTING FROM HERE TO THERE

The concept of moving from safety to resilience is compelling. The reality of how to do it is complex. There is a need to settle on a set of consistent performance goals that are fully incorporated in the design standards and codes for new buildings and lifeline systems. These standards and codes need to be adopted by all affected jurisdictions and enforced by knowledgeable building officials and inspectors. The design and construction professions need to fully embrace the change, learn the new procedures that are needed achieve the resilience goals and become accustom to constructing projects to a revised set of standards. Existing buildings and lifeline systems need to be inventoried, their fragilities established, and a key subset of underperformers slated for mitigation.

Setting and achieving resilience goals may begin at the local level, but they will not be fully effective if they are not developed and implemented in a consistent manner nationally. A community's ability to recover depends on regionally distributed lifelines and national resources. The federal government should take the lead in establishing the performance goals needed for recovery along with incentives for states, regions and communities to adopt and implement them. These goals need to be set for the full set of natural hazards that the nation faces, including seismic. Continuous research related to how to effectively achieve resilience needs to be funded at the federal level along with continuous funding for the development of national design standards and model building codes. Specific, first order attention needs to be given to the nation's lifeline systems and their interdependencies.

The new generation of design standards and codes that are needed must incorporate transparent performance levels and consistent hazard levels to be effective. The public and their policy makers will make the necessary decisions to change from a safety focus to a resilience focus if given a clear and understandable vocabulary to discuss seismic safety, realistic goals and consistent standards. In the United States, ASCE 7, 31 and 41 and the standards used for lifeline design need to be brought into consistency in terms of vocabulary and transparent performance goals.

Building codes and building officials are the first line of defense. To be successful, code adoption and enforcement must be universal throughout the nation. The recent earthquake in Haiti, as well as many earthquakes that preceded it, demonstrate that communities and their developers cannot be expected to voluntarily build to a consistently safe level, let alone the new resilience level that is needed. To achieve this safety level, local communities need financial assistance and incentives to implement the needed standards and codes, and lifeline providers need specific design standards that include appropriate performance goals.

Changing the culture of the design and construction industry is perhaps the toughest challenge. The significant strides that have been made over the past 100 years are evidence that it can be done. It appears that change has often come after a major disaster. Those who write standards and codes evaluate the disaster and determine what changes are needed. The changes are incorporated into the standards and model codes in time, and when enforced, actually change the way buildings and systems are constructed. It is a slow process that needs to be accelerated through national consistency, federally sponsored incentives, and local adoption.

The existing inventory of buildings and systems will remain the greatest challenge. New standards and codes will eventually lead to a resilient built environment, but it may take hundreds of years and multiple natural disasters. Since only a handful of buildings and systems need significant mitigation, it makes sense to identify those and provide the resources needed for rehabilitation. Particular attention needs to be given to the “killer” buildings - those that will collapse and cause extensive loss of life. In addition, buildings and systems that are needed for emergency response and governance need to be rehabilitated along with residential and neighborhood structures so that residents can shelter in place and get back to work quickly.

Existing lifeline systems are a unique challenge. They are constructed and operated by both public and private entities that face extensive regulation and limitations. Their business models are focused on economic viability within the communities they serve with little opportunity to consider their larger role in the regions they serve. National, regional, and local lifeline councils are needed to bring the operators together, define the interdependencies in their operations, and set priorities for rehabilitation that match the recovery needs.

CONCLUSION

In many ways, the tools and procedures to create disaster resilient cities exist and are continually being refined. Achieving resiliency nationwide, however, will require a new application. Modifications to the current building codes, alignment of the lifeline systems around common performance objectives, and strong community support for adopting the policies are needed. Deficient buildings and systems need to be mitigated, and new buildings and systems need to be designed, to the minimum performance levels that are needed.

Making such a shift to updated codes and generating community support for new policies is not possible without solid, unified support from all levels of government and the private sector. The federal government needs to set performance standards that can be embedded in the design codes, provide financial incentives to stimulate mitigation that benefits the nation, and continue to support research that delivers new technologies that minimize the cost of mitigation, response and recovery. Regions need to identify the vulnerability of their lifeline systems and set programs for their mitigation to the minimum level of need. Localities need to develop mandatory programs that mitigate their built environment as needed to assure survival. The private sector is expected to respond and cooperate as the reality is defined in clear and compelling terms, and financial incentives are provided to support the community needs.

The overarching benefit of the shift from safety to resilience is the ability of communities to take the hit of a natural disaster in stride and recover to a new though recognizable normal without loss of life, their economies, jobs, or cultural heritage.

CONTRIBUTORS

The thinking behind the shift from safety to resilience has been in process for at least 40 years. Triggered by the 1971 San Fernando earthquake, the concept of building better has been

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