5. Building Sector

5.1. Introduction

Building codes and standards have primarily focus on life safety of occupants during major natural hazard events, specifically in their structural design criteria. Early building codes addressed routine environmental design loads for frequent hazards such as wind and snow. The hazard design load and self-weight and occupancy live loads were used to design a structure. This approach produced structures that withstood routine, moderate hazards. However, the 1906 San Francisco Earthquake demonstrated that some hazards induced large forces that were difficult to resist without any structural damage. This led to a philosophy of designing buildings for major hazards, such as earthquakes, that remain stable with some structural damage but do not collapse.

As scientific understandings of natural hazards evolved, return periods for the given hazards were selected to define the loadings, as opposed to specific loadings determined based on judgment and experience. The design intention, however, was still for the individual elements of the structure to have a margin of safety against failure when subjected to that specific load. Code provisions were developed with the intent of most buildings having the same level of structural safety. However, in actuality, this level of safety was greatly influenced by the selected construction material and local building regulations and practices.

As codes evolved, two things became apparent – certain buildings need to perform to a higher level of safety and other buildings, because of their use, should retain their pre-even function. For example, model building codes specified that schools and buildings with very large occupancies be designed for higher forces, in an attempt to provide a greater level of safety than typical buildings. Additionally, buildings such as unoccupied agricultural storage facilities were allowed to be designed for lower forces, permitting them to have a lesser level of safety than a typical building for natural hazards. Hospitals, first responder facilities, and emergency operations centers are classified as buildings which should have some ability to return to their pre-disaster function following the design hazard level. This delineation of buildings into different categories has evolved into the four Risk Categories found in current national model building codes specifically the *International Building Code*.

While the model building codes specify minimum requirements that are meant to be applicable throughout the country, many localities draft their own building codes or incorporate modifications to the model codes in to achieve specific goals for local or regional hazards. In areas of Florida, building codes were changed to require more hurricane resilient construction –a requiring certain types of roofing materials, stronger windows and doors, and greater inspection and enforcement.

Following the 1994 Northridge Earthquake, where there was little loss of life but extreme economic losses, there was a move toward performance-based design and evaluation of buildings. It was felt that engineers should be provided with tools to allow for designing buildings beyond the prescriptive provisions in the building codes and instead target an intended performance to a specified hazard. That approach led to the definition of discrete building performance states of Operational, Immediate Occupancy, Life Safety, and Collapse Prevention. With this came the recognition that the nonstructural systems in a building, such as the architectural element and the mechanical, electrical and plumbing systems, contribute significantly to building performance, especially in critical facilities that communities expect to be functional.

One major design criteria missing from model building codes is performance goals that are needed for post-disaster recovery. Many municipality's emergency plans are based on certain building being available within a set period of time from the onset of the disaster. While this is not at odds with the current Risk Category or performance-based design approach, it does present challenges because some buildings' current design parameters may not align with community needs. The major difference between this need and typical performance-based design approaches is the use of downtime as the key performance metric.

This chapter focuses on establishing a basis for setting performance goals for buildings within a community. Existing codes and standards provide minimum requirements. Until recovery and other resilience concepts are incorporated into the codes and standards, communities will need to make decisions to go beyond the model building code that will provide a built environment that can meet its resilience goals.

5.2. Performance Goals

The resilience goal matrices in Chapter 2 are based on specific clusters of building and infrastructure being brought back on-line at specific intervals following the disaster. Chapter 2 contains a specific example of how a San Francisco public policy think tank, SPUR, adapted a resilience matrix for a major earthquake affecting San Francisco. The concepts used in that example and in Chapter 2 provide a basis for other communities to determine their needs post-disaster. The needs of different types buildings identified in the matrix are discussed in this section.

5.2.1. Government

In most communities, the primary emergency operations center, airports, and first responder facilities are government owned buildings. These buildings support and shelter the people and equipment that provide essential services and must remain operational during and after a major disaster event. Communities expect and plan for these facilities to be operational during and after hazard events. Therefore buildings for emergency operation centers, police and fire stations, water and wastewater treatment facilities, and emergency shelters need to remain operational (Category A as defined in Chapter 2).

Currently, most of these essential buildings would fall under the Risk Category IV in the *International Building Code*, which requires the highest design forces and has some provisions for nonstructural systems remaining operable post-disaster. Some are Risk Category III, which requires higher design forces, but with fewer specific nonstructural system requirements. However, as will be discussed in Section 5.5, there are still significant gaps between the current model building codes and standards' requirements and providing truly functional buildings following a major disaster.

There are other government buildings which are may not be immediately needed following a disaster, but a community may determine to be critical to recovery, such as a City Hall or county administrative building, schools, mass transit stations and garages and community centers. A possible goal would be to have these types of government buildings functional in about a month, depending on their role in the community, following the disaster. In some cases these buildings are designed as Risk Category III while other are designed as Risk Category II (typical buildings). Neither Risk Category II or III have specific provisions which would provide a high level of confidence that the building could be returned to operation within a month. In the Chapter 2 performance vernacular, a performance level for these types of buildings might be Category B – Safe and usable during repair. This may be the performance Risk Category III is delivering, but not what Risk Category II is intending.

5.2.2. Healthcare

Emergency medical facilities are critical to response and recovery efforts following a major disaster. Therefore hospitals, other such facilities, and their supporting infrastructure need to be operational (Category A) following the disaster. Currently, hospitals are designed to Risk Category IV requirements (Occupancy Category IV prior to 2010), with some local communities or federal agencies placing additional requirements on them. For example, the state of California requires that all hospitals, regardless of location or ownership (municipal or private) have their designs reviewed and construction overseen by a state agency.

Other healthcare facilities, like doctor's offices and outpatient clinics, need not be immediately available, but a community may determine that they are needed shortly after the initial shock of the disaster. Therefore medical office buildings may be designed to be safe and usable during repair (Category B. In most cases they are currently designed as Risk Category II buildings, meaning they have no major design requirements beyond preservation of safety without consideration for post-disaster function. Nursing homes and residential treatment facilities that house patients that cannot care for themselves independently may also need to be immediately functional after the disaster the designed the same as acute care hospitals.

5.2.3. Schools

Many communities, as reflected in the IBC, have concluded that K-12 Schools should be designed to a higher performance than typical buildings because they have large assemblies of children. In many localities, school gymnasiums or the school buildings are also designated to serve as emergency staging areas or emergency shelters. Additionally, the research that went into the SPUR Resilience City Initiative found that there is a perception that if children can return to school, then things are getting back to normal and their parents can return to work. Thus, expeditious resumption of function is important for schools across a community.

There is a dichotomy of performance requirements for a school. On the one hand providing enhanced safety and returning to operation quickly would place a school in Category B – safe and usable during repair. However, the expectation that it could be used as an emergency shelter, would in turn place it in Category A – operational. The current Risk Category III provisions, to which most K-12 schools are designed, may provide Category B, but definitely will not provide Category A performance. Therefore, it is recommended that any school that is going to be designated as an emergency shelter be designed for Category A requirements, which would mean being designed or upgraded to a higher level than is commonly used today, possibly Risk Category IV requirements per the IBC or greater.

Higher Education facilities have typically been grouped into the same category as K-12 schools and follow similar design standards. Research Universities often have the added concern for the protection of their research facilities and long term experiments.

5.2.4. Residential

Current thinking suggests that residential buildings and neighborhoods should be designed to provide shelter for a significant portion of the population following a disaster. They need not be functional, like a hospital or emergency operation center, but they do need to safely house their occupants to accelerate the ability of the workforce to return to work. The significant loss of housing stock led to the migration of a majority of the work force following Hurricane Katrina's impact on New Orleans (reference needed). Such a "shelter in place" performance level is a key component of the SPUR Resilient City initiative and prompted the City of San Francisco to mandate a retrofit ordinance for vulnerable housing.

In addition, an effective response to most disasters requires supplemental first responders and other personnel for a period of time. If the majority of the residential buildings are not functional, then the demand for emergency shelter competes with the demand for housing temporary responder and recovery workers. Thus communities may designate residential buildings to be designed to safely provide shelter.

Currently multi-unit residential structures are designed to Risk Category II provisions, except in certain cases where the number of occupants is quite large, over 5,000 people, then they are designed to Risk Category III. Risk Category II may not provide the requisite level of performance in a major disaster.

Most one and two family dwellings are not engineered, but rather are built to the prescriptive requirements of the *International Residential Code*. There has been some debate as to whether the IRC provides comparable performance to the *International Building Code.* In some cases, such as the Loma Prieta and Northridge earthquakes, one and two family dwellings performed as well as, or in some instances better than, engineered buildings. While in other instances, specifically hurricanes and tornadoes, one and two family dwellings have not performed as well as engineered buildings. Whether there is a discrepancy in performance between the IBC and the IRC is something that should be investigated further, because of the importance of residential housing.

5.2.5. Business and Services

While it would be ideal to have all community businesses open shortly after the initial disaster , it may not be economically practicable. Most buildings housing offices, retail, and manufacturing are currently designed to Risk Category II. As will be discussed in subsequent sections the performance of Risk Category II buildings is really based on safety, but not functionality. That is not to say all commercial buildings are designed to the code minimum, because many are designed for higher performance, but for the purpose of this framework it is assumed that most are.

It is recognized that certain types of commercial buildings are likely critical to the post-disaster recovery effort and the community needs to designate which perform to a higher performance level so they can be available in an appropriate period of time following the disaster. Each community needs to select design and recovery performance goals for its businesses and services, depending on their role in the community during the recovery period.. Some businesses and services that commonly are essential to recovery include:

- Grocery stores – It is important that people be able to get food and water following a major disaster. Additionally, major grocery stores typically have robust distribution networks outside of the affected area that can be tapped to bring supplies into the area. While the common preparedness recommendation is for people to have 72 hours of food and water on hand, the potential for disruption beyond the first three days is great in major natural disasters. For example, the Oregon Resilience Plan recommends two weeks of food and water.
- Banks or financial insinuations –Banks or at least structures housing automated teller machines are important because they provide people with access to money.
- Hardware / Home improvement stores – These stores are critical to the post-disaster recovery effort in their ability to provide building materials to aid on the reconstruction, and even emergency shoring of damaged buildings.
- Gas Stations and Petroleum Refineries – Many communities have been planned in a manner which necessitates that residents have automobiles to carryout basic functions, like shopping and commuting to work.
- Buildings that house industrial and hazardous materials.

5.3. Building Codes and Standards

Communities primarily consist of existing buildings. The expected performance of each building depends the codes and standards in-force at the time of construction, as well as the level of maintenance. The mix of building types, construction, and age can create significant challenges when developing plans for a resilient community. Current design criteria for new construction is also critical, as it forms the basis for future resilience planning.

5.3.1. New Construction

The engineering standards currently used throughout the country for the design of building are focused on preserving safety of occupants in major natural hazard events. For some hazards, such as wind, snow and rain, the intention is for the building to sustain no damage under the design event by requiring that each element remain elastic. For other hazard events, such as earthquakes, the design intention is for typical buildings to provide life safety, which allows structural damage but not collapse. Thus, while a building will protect occupants, it may need to be demolished after a seismic event if sufficiently damaged. Structures are designed for performance relative to a primary design hazard, and checked for other hazards. The expected performance for these loads is briefly described below. Note that recovery goals are not currently a part of building design and performance goals.

Wind hazards. Today, for wind load designs ASCE 7-10 prescribes design wind speeds based on different return periods. The return periods are tied to the Risk Category of the facility. For Risk Category I facilities, typically unoccupied agricultural buildings, the return period is 300 years. For Risk Category II facilities, typical buildings and other structures, the return period is 700 years. For Risk Category III facilities, schools and high occupancy structures, and Risk Category IV facilities, hospitals and emergency responder facilities, the return period is 1,300 years. The wind speeds derived from these return periods are based on extratropical winds and hurricane winds. Tornadic wind speeds are not currently addressed.

The majority of the wind design requirements are for the structural frame and the cladding. There are some requirements for attachment strength of nonstructural components. Requirements for serviceability and functionality are not explicitly codified, but are indirectly addressed through elastic design methods at specified wind speeds for desired performance levels. The International Building Code requires consideration of a drift limit under a reduced wind load (the factor used intends to approximate the 100-year return period wind). There are no explicit structural design requirements to preserve the building envelope so post-disaster function is not impacted, but there are some prescriptive requirements on the requirements of doors and windows. Nor are there requirements that exterior equipment must be functional following the design windstorm.

Snow hazards. Snow design uses a 50 year mean recurrence interval for ground snow loads. It is increased with an importance factor for higher Risk Category structures.

Rain hazards. Rain design uses a 100 year rain storm as the design hazard, with loads increased by 60% to account for uncertainty in predicting rainfall in a major event. However, the majority of the rain design provisions relate to providing proper drainage and stiffness to the roof to prevent ponding. There are no code requirements to that in a design rain event the building envelope must maintain its ability to keep water out. In many instances this is accomplished without explicit code requirements because of the liability seen with water intrusion and the adverse effects of it, such as mold.

Flood hazards. Flood design provisions for all structure are typically based on a 100-year mean recurrence interval for flood elevation, though 500-year flood elevations are recommended for design of critical facilities. Recommended practice is to locate structures out of the flood zone, or to elevate the structure above the design flood elevation. For structures subject to flood forces, the current provisions provide methods to resist flood forces, but may not necessarily to preserve functionality of the building.

Seismic hazards. The performance of buildings during earthquake events is most developed of the hazards in the building codes and standards. Since the beginning of earthquake design, it has been recognized that designing for the hazard elastically, as is done with other hazards, would not be practical or economical. Therefore the approach adopted prescribed forces and design requirements which would allow the building to be damaged, but not collapse. Following the 1971 San Fernando earthquake it was recognized that essential facilities like hospitals needed to be designed to a higher standard, to significantly improve their likelihood of remaining functional following the design earthquake. A design earthquake with approximately a 500-year return period was chosen and used until the early 2000s, when it was decided that a longer earthquake return period was needed to capture the seismic hazard in other parts of the country. Since then the maximum considered earthquake shaking hazard has been around a 2,500 year return period.

Recently, there was a shift from a uniform 2,500 year hazard to a risk targeted hazard level. By setting a uniform risk of 1% probability of collapse (or a 99% probability of not collapsing) in 50 years, the return period required to achieve that goal varies based on the seismicity at a specific location. For most parts of the country the return period is not significantly different than 2,500 years.

A very important distinction between seismic design provisions and other hazards is the emphasis placed on the design of nonstructural systems. All nonstructural systems have bracing requirements. In addition to the bracing requirements, nonstructural systems in essential facilities or those systems that relate to the life safety system of the facility have requirements that they must maintain function or return to function following the design earthquake shaking hazard. The design earthquake shaking level is currently defined as 67% of the Risk Targeted Maximum Considered Earthquake shaking level.

Fire hazards. Fire hazards are addressed prescriptively through fire protection requirements for structural members or other construction standards that are typically under the purview of the building architect, not the structural engineer.

Man-made hazards. Currently codes and standards do not have explicit structural design requirements and design standards for explosions or impact events. There are some nominal provisions that attempt to provide robustness to arrest the spread of damage so a disproportionate collapse does not occur. There are many requirements in the IBC that require facility layout and hazard mitigation measures which attempt to prevent explosions of building contents.

5.3.1.1. Performance Levels

This section is under development. Text will be included in a future draft.

5.3.1.2. Hazard Levels

This section is under development. Text will be included in a future draft.

5.3.1.3. Recovery Levels

This section is under development. Text will be included in a future draft.

5.3.2. Existing Construction

Existing buildings pose an even greater challenge than new buildings. For new buildings, the codes can be amended or re-written and while construction costs may increase the new buildings would therefore be designed for the state of the practice. Retrofit of existing buildings to the state of the practice level of resilience, in contrast, can require significant financial commitment and necessitate major disruption to the building's function. That tends to dissuade building owner from retrofit.

When existing buildings are evaluated for their expected performance relative to resilience goals and required retrofit actions, the standards for new construction are typically applied for the structural design which often lead to very conservative results. However, the recent advancement in performance-based engineering, has led to the development of specific standards for existing buildings with regards to evaluation and retrofit.

One of the biggest impediments to retrofit of existing buildings lies in the conservatism embedded in the current engineering codes and standards. Under-predicting a building's performance in a given hazard because the standards are too conservative can lead to significant retrofit requirements. Those requirements can make the retrofit economically unappealing to the building owner. Therefore, a major impediment to mitigating existing building natural disaster hazards that needs to be addressed is refining the engineering standards to allow simple, focused identification and retrofit of the most dangerous or most significant existing building hazards.

5.3.2.1. Performance Levels

This section is under development. Text will be included in a future draft.

5.3.2.2. Hazard Levels

This section is under development. Text will be included in a future draft.

5.3.2.3. Recovery Levels

This section is under development. Text will be included in a future draft.

5.4. Building Stock Performance

Engineered buildings have performed well for most hazards. In many instances, the intended performance of most buildings, especially the most recently designed ones have been satisfactory or have not yet been tested with a design event. The performance of older buildings and un-engineered or prescriptively-designed buildings has been more varied. An improved understanding of existing building stock performance following major disasters is needed.

5.5. Resilience Needs

As discussed previously there are a number of resilience gaps in the current inventory of buildings that involve both the standards used for the design of new buildings as well as the need to retrofit some buildings. As part of the process, communities need to prioritize the mitigation of the gaps that exist and develop programs that address closing those gaps.

5.5.1. Standards and Codes

The most significant challenge for disaster resilience standards development is aligning the design philosophy of the all the environmental hazards with the intended performance goals. As was discussed earlier, wind, ice, rain and snow are based on an element specific reliability at different hazards level, while seismic is calibrated based on a system reliability for another hazard level. The hazards designed with element specific reliability may have greater system reliability than those hazards where system reliability is the only design goal. The inability to accurately predict what is safe enough versus what is truly dangerous has led to impediment to addressing the hazards posed by the most dangerous existing building.

In addition, there are few provisions for facility function preservation for most hazards. Seismic has the most significant requirements, in part because it has established nonstructural requirements. For other hazards structural and nonstructural requirements to preserve function in essential facilities are needed. This is a significant issue that needs to be addressed, because a facility's structure may be undamaged, but if it cannot perform its intended function because critical systems are not functioning the recovery is hindered.

Coupled with the lack of function preservation provisions is the lack of tools that engineers can use to estimate a building's reliability of being returned to function in a given time period. Disaster plans and the Chapter 2 resilience goals assume that specific buildings are brought back online with a set period of time for each hazard. Without the ability to assess this, engineers are typically left with the binary distinction of whether or not a building meets Risk Category IV or Immediate Occupancy criteria (similar to Category A), which are typically too conservative for Category B facilities.

Another overarching issue related to existing engineering standards is how to bridge the gap between deterministic performance-based goals, like those enumerated in Chapter 2 and the probabilistic basis of the hazards. In many cases this has led to overly conservative provisions because of the goal of having significant certainty in the hazard outcome. Conversely, the deamination of what is an acceptable level of reliability is difficult to quantify. For a dense, urban area, there may be several hospitals within an affected area of a disaster. Therefore the reliability of each hospital need not be 100%, because the loss of one hospital may not significantly hinder the resilience of that community. On the other hand, a rural community may have one hospital for the entire county and that hospital must have a significantly higher reliability. Designing for a very high reliability of safety and return to function for all new buildings has not been a significant issue, but allowing lesser reliability of return to function for redundant facilities may be a way to alleviate some of the burden of evaluation and retrofit costs for existing buildings needed to achieve the resilience goals..

For specific hazards, there are some disparities in the magnitude of hazard events that is currently being designed for. Flood loads are currently the most significantly out of harmony with the other hazards. The fact that an essential facility is designed for a 1,700 to 3,000 year return period hurricane, but need only be designed for a 100-year storm surge flood is disproportionately unbalanced. The flood design hazards for essential facilities need to be increased, possibly significantly.

Currently tornadoes are not explicitly addressed in the building codes for a number of reasons. There are beliefs that the probability of a tornado striking a specific building is so low that it need not be explicitly considered or that nothing can be done to resist tornadic events. The commentary to the wind design provisions in ASCE 7 discusses this issue in more detail. However, a significant number of communities are affected by tornadoes every year, and design guidance to improve performance and recovery of the built environment is needed.

5.5.2. Practice and Research Needs

This section is under development. Text will be included in a future draft.

5.6. Summary and Recommendations

This section is under development. Text will be included in a future draft.