Risk Perception in Performance-Based Building Design and Applications to Terrorism-Resistant Design

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Abstract: As buildings have become larger and house more people, political and societal issues have become more complex, and risks associated with occupying buildings have changed. In particular, since the terrorist attacks of 2001, the anxiety levels and perceived risks of building occupants (especially occupants of tall, high-profile buildings) have increased. These perceived risks include risks of terrorist attacks, natural disasters, the possibility of bomb threats, and catastrophic fires. The public’s perception of risk is already incorporated into building design codes and performance-based design (PBD) methods for such hazards as earthquakes and fires—explicitly in some cases, implicitly in others. Risk perception will clearly need to be addressed in the design of buildings, as trade-offs in “acceptable” risk versus cost must be made. As terrorism represents a constantly changing design challenge, and is a target-specific hazard, as opposed to a location-specific hazard, it seems unlikely that prescriptive code requirements will be entirely effective at addressing this hazard. PBD codes are a promising approach for design issues that deal with such “cutting-edge” concepts.

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Introduction

Risks have always been associated with buildings. However, as buildings become larger, house more people, and are seen as potential targets of attack, occupants perceive an increase in risks associated with occupying buildings. In particular, since the terrorist attacks of 2001, the anxiety level and the perceived risk of occupants of buildings (especially tall, high-profile buildings) have increased (Bruder 2003; Kirkpatrick 2002; McCauly 2002). These perceived risks are not necessarily limited to terrorist attacks. Building occupants are now more attuned to terrorist threats and the possibility of bomb threats or catastrophic fires, as well (Kilman et al. 2001).

Risks from earthquakes have been present and accepted for some time in certain parts of the country. Seismic-resistant design codes in the United States have become relatively effective at providing life safety to building occupants, but with large economic losses in recent earthquake events, demand has developed for a system whereby performance objectives in addition to life safety can be explicitly defined and met and economic risks addressed (Hamburger 2001). This is the reasoning behind performance-based design (PBD) codes in seismic engineering.

Fire design codes in the United States are also in a period of change (Van Rickley 1996). This is part of a growing trend around the world to increase design flexibility, lower building costs, improve building safety, and decrease fire losses (FMR 2001). In response to these new requirements, a PBD philosophy has been developed for the design of buildings for fire. New design codes are attempting to integrate human factors, risk perceptions, and transparent, quantifiable performance goals into the design process (Meacham 1999).

Terrorist attacks as a threat to buildings are a threat that most design codes have not addressed in the past, but which have clearly become more important (Gilbert et al. 2003), especially for certain types of buildings. Terrorism has become an issue that causes anxiety and worry in the minds of the public. As building codes are in existence for the benefit and protection of the public, it seems reasonable that codes should take into account the perceptions and fears of the general public when designing for all hazards, including terrorist threats.

This paper will discuss the current applications of PBD to seismic and fire hazards, and the extension of the PBD concept to terrorist attack hazards, as well as the ways in which the perception of risk is addressed in each of these areas.

Performance-Based Design Overview

Codes for designing civil engineering structures have historically been prescriptive. That is, the codes specify the loads and the minimum levels of various aspects of the design. The steps of the design, materials to use, construction methods, and levels of load (or hazard) are explicitly prescribed for the designer, while levels of safety are generally implicitly prescribed (through safety factors, load and resistance factors, occupancy factors). Prescriptive provisions do not provide procedures for predicting the actual performance of a given building design, or for varying the level of performance intended for a particular design (Whittaker et al. 2003).

By contrast, in PBD methods, a desired level of building per-
formance may be selected, along with appropriate measures of that performance, and the designer must then determine a means to provide the chosen level of performance, as well as prove that it is achieved. PBD is generally used to design buildings to performance levels that exceed the minimum standards for life safety set by prescriptive codes (Post 2005). This means that building owners who, for example, would like to design buildings that will not only save the lives of the occupants, but also allow continuation of their business after an earthquake, can do so. The main feature of PBD methods is the performance objective selected before the design is begun. This performance objective consists of a “design event” the building will be designed to resist, and a performance level that the building must achieve given that the design event occurs (Whittaker et al. 2003). The performance objective must also include an evaluation statement and criteria to determine whether the objective is met (Hattis and Becker 2001).

One of the difficulties with existing systems of PBD is the fact that the various disciplines that employ PBD methods do not interact with each other. In fact, even the terminology used in the various disciplines is different. The PBD methods currently used in seismic design and fire safety design of buildings are reviewed in the following.

### Performance-Based Seismic Design

Building codes have traditionally been developed by a method of observation followed by refinement. In earthquake design, damage from an earthquake is observed, and then the codes are refined to reflect what was learned from the observations. Seismic design codes in the United States are intended first and foremost to protect the lives of building occupants by preventing collapse and falling debris in the event of a large earthquake (SEAOC 1995). In recent years, design and construction have improved to the point that other performance factors have become important, such as minimization of damage, business interruption, and downtime during more common, less severe earthquakes (Hamburger 2001). One of the basic goals of performance-based earthquake engineering is the provision of designs with uniform risk. In traditional methods, “seismic design in the United States is based on the use of uniform hazard and not uniform risk” (Floren and Mohammadi 2001). In order to design buildings with uniform risk, probability of occurrence must be taken into consideration in addition to the hazard level.

In prescriptive earthquake design, stresses and member forces are calculated based on a code-specified applied lateral load. These member forces are limited, thus dictating the size and number of members. Uncertainty is generally taken into account by selecting the design loads based on recurrence intervals or a maximum expected ground motion (see, e.g., FEMA 2000). In the case of the Structural Engineers Association of California (SEAOC) Performance Based Seismic Engineering of Buildings (SEAOC 1995) and most other PBD seismic codes, the performance levels are damage states. A performance objective is the achievement of a chosen performance level at a given design earthquake level. Fig. 1 illustrates the selection of a performance level and design level. For example, a designer could choose to achieve a performance objective of Life Safe for a Rare earthquake. Table 1 shows another example of target performance levels and earthquake hazard levels from FEMA (Federal Emergency Management Agency) 356, Prestandard and Commentary for the Seismic Rehabilitation of Buildings (FEMA 2000). In FEMA 356, the hazard level (exceedance probability) is correlated with an equivalent acceleration response spectrum or time history.

In seismic design, performance levels are most often levels of stress, loads, displacements, limit states, or target damage states. A potential extension of this concept is to create performance levels based on maximum numbers of injuries or fatalities, using acceptable risk criteria. These criteria are implicit in the “life safety” performance levels currently used in seismic design.

### Performance-Based Design of Buildings for Fire

A number of countries have, or are currently working toward, performance-based fire design codes, including Australia, Canada, Great Britain, Finland, France, Norway, Sweden, New Zealand, Japan, The Netherlands, and the United States (FMR 2001; Johnson 1996; Van Rickley 1996). Performance-based fire design is an engineering approach based on previously established and agreed-upon fire safety goals and objectives to be met for various deterministic and probabilistic fire scenarios. This approach is then used in “a quantitative assessment of design alternatives that is used to evaluate the expected performance of buildings, of systems, of components, and of occupants during fires” (Meacham 1997). The process consists of goals, objectives, performance requirements, performance criteria, design fire(s), design alternatives, review, and acceptance.

Goals are qualitative statements of desired performance. Examples of basic performance goals of a fire safety design code are: (1) safe egress for occupants; (2) safety for fire fighters; (3) prevention of fire spread and protection of property; and (4) safeguarding the environment from the adverse effects of fire and fire spread (Meacham 1997).

Objectives are quantifiable characteristics chosen to provide some means of determining whether the goals are being met. A goal of building design for fire (e.g., “protecting building occupants in case of a fire”) may be difficult to quantify in terms of design parameters. Thus, objectives that are easier to quantify are developed (e.g., “allow adequate time for safe egress”). Next, quantifiable, measurable or calculable performance requirements are established (e.g., “structure shall maintain adequate load carrying capacity for time necessary to safely evacuate”). Perfor-
Earthquake hazard

<table>
<thead>
<tr>
<th>Level designation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% chance of exceedance in 50 years</td>
<td>Building remains safe to occupy, retains pre-earthquake strength and stiffness</td>
</tr>
<tr>
<td>2500 year return period</td>
<td>Structural components suffer damage, but building retains margin of safety against partial or total collapse</td>
</tr>
<tr>
<td>75 year return period</td>
<td>Structure suffers damage, continues to support gravity loads, but retains no margin against collapse</td>
</tr>
<tr>
<td>Not considered</td>
<td>Does not address performance</td>
</tr>
</tbody>
</table>

Performance criteria are essentially the threshold values for the performance requirements (e.g., “floor assembly shall maintain a capacity of 100 psf for 20 minutes”). In decision analysis, objectives are called “means objectives,” goals are called “ends objectives,” and performance requirements are called “attributes” (Hammond et al. 2002). These terms may differentiate the various components of a PBD more clearly.

Next, design fires are chosen, followed by development of design alternatives, which are evaluated against the performance requirements under design fire loadings. The prescriptive code requirements can be used as a performance baseline, but more than one design alternative is generally considered. Meacham points out that it is important to know whether the prescriptive requirements would meet, exceed, or fall short of the chosen PBD design objectives (Meacham 1997). Once a design alternative is chosen, it must be thoroughly documented to support the approval process.

Issues with review and acceptance need to be resolved before PBD can be fully utilized for fire safety design. Either a building official must approve the design, or it must be subjected to a peer-review process (ICC 2003b). The peer-review process adds cost and delays to a project. A survey in 2000 found that 60% of building-code officials would seek assistance to review a PBD (Post 2005). In New Zealand, approval can be achieved by use of an approved “verification method,” an “acceptable solution,” or an “alternative solution.” An approved verification method is an agreed-upon and approved calculation method. However, no approved verification method exists for fire design. An acceptable solution is essentially a prescriptive option that has been designed to meet the requirements of the PBD code. An alternative solution (in which the engineer designs a system not given in the code) most closely resembles what is generally understood by PBD (Buchanan 1999). The issue of approval needs to be further addressed for all PBD codes.

Arguments for the Use of PBD

PBD allows owners and designers of buildings the flexibility to choose performance levels appropriate to their specific requirements (Hamburger 2001). It provides the ability to “clearly identify and precisely define quantitative performance objectives” in the design of buildings (May 2004), and achieves predictable performance (SEAOC 1995). This allows a more informed choice of trade-offs between cost and performance, and allows owners of buildings with different uses and different needs to specify differing performance objectives for their buildings. PBD also allows engineers to design a higher level of safety, or any type of performance for the building, rather than merely following prescriptive codes that specify a baseline level (Liew 2004). This flexibility will allow different approaches and solutions to meet the minimum performance levels, and will allow more creative designs that more effectively balance performance with costs. According to one survey (Van Rickley 1996), building code professionals strongly agree with the necessity of utilizing performance-based codes, and with basing building design decisions on potential risk to occupants and to adjacent occupancies. The same concept could be applied not only to risk, but to costs of operation, or level of productivity in a building. PBD methods can also significantly reduce the size and complexity of building codes, and hence lead to more efficient designs with clear indications of the level of performance provided by the design (Van Rickley 1996). Finally, PBD methods are able to directly address the interaction of building occupants and their characteristics with the occurrence of an extreme event (Meacham 1999).

Current Use and Development of Performance-Based Design

One of the first documents to codify PBD was the Vision 2000 project undertaken by the SEAOC. This project resulted in two volumes of Performance Based Seismic Engineering of Buildings (SEAOC 1995), which are widely cited in many PBD documents. The Applied Technology Council has published a methodology for the seismic retrofit of concrete buildings (ATC 1996). FEMA has also developed a number of documents that incorporate PBD in some form. For a list of these documents, consult FEMA 356 (FEMA 2000) (pp 1-3 and 1-4). These documents cover topics such as seismic evaluation and rehabilitation of existing buildings, and recommended provisions for new structures. Finally, the International Code Council (ICC) has published their Performance Code for Buildings and Facilities (ICC 2003a), which is a completely performance-based building code.

A number of PBD fire design codes have been developed and published. Some examples include the Building Construction and Safety Code published by the National Fire Protection Association (NFPA 2003), the EPCOT Fire Prevention Code used by the Reedy Creek Improvement District in Florida (RCID 2002), the International Fire Code (ICC 2003b), and numerous codes in other countries. The proliferation of documents indicates that PBD methods are becoming accepted in fire protection engineering.
Risk Perception in Building Codes

Risk perceptions are incorporated, explicitly or implicitly, into codes and PBD methods for seismic and fire safety design. A psychometric (the branch of psychology that deals with developing quantitative tests for the measurement of psychological variables) method has been developed for quantifying and predicting people’s perceptions of risks (Slovic 1987; Slovic et al. 2004). This method places a hazard in a two-dimensional “factor space.” Fig. 2 presents various hazards in this factor space. The location of a hazard on the horizontal axis indicates its level of “dread risk.” Dread risk is characterized as uncontrollable, involuntary, and inequitable, with consequences that are far-reaching, catastrophic, or fatal, presenting high risks to future generations, and not easily reduced. The location on the vertical axis describes how well understood the hazard is perceived to be. If a hazard is observable, with an immediate effect, well-known to science, familiar to people in general, or one that is obvious to those exposed, it will tend to be located lower on the vertical axis. Fig. 2 presents an aggregated version of this factor space [including hazards from both Slovic et al. (2004) and Slovic (1987) studies].

Risk Perception in Seismic Design

Risk perceptions are implicit in building codes in the use of an “importance factor” or “occupancy factor.” Importance factors are generally based on the type of use to which a facility will be subjected. In the International Building Code, “Seismic Use Groups” are defined. These groups are described in Table 2 (ICC 2000). The seismic use factor is then effectively used as a multiplier for base shear (earthquake load) to be resisted by the building. This is termed a load factor, but can be thought of in terms of an additional safety factor for earthquake damage or life safety for each category of structure. Examination of Table 2 reveals that psychometric risk factors are implicit here. Categories II and III represent facilities with characteristics that would rate high on one or more of the factors that contribute to dread risk (Slovic et al. 2004). Table 3 illustrates this relationship.

A survey done in Portland (Flynn et al. 1999) indicated that earthquake risks were ranked high by members of the general public in terms of their severity or importance. This reflects the fact that earthquakes are uncontrollable, their effects are not equitably distributed among the population at large (e.g., those...
without enough capital to retrofit their buildings are affected much more significantly than those with brand-new earthquake-resistant buildings), and, have the potential to be catastrophic events. However, the public typically tends to feel less concerned about natural hazards than about man-made, technical hazards (Flynn et al. 1999). In addition, there is a perception that the public is adequately protected from earthquakes by existing building codes, even though most remain unaware of the performance standards upon which those codes are based, and of the actual behavior of a building subjected to a severe earthquake (Hamburger 2001). This feeling of adequate protection and the belief that existing building codes were developed based on strong knowledge of the consequences of an earthquake indicate that earthquakes are viewed as representing risks that are relatively well known to science and, seemingly, relatively easy to reduce through retro fitting, or following the building code during construction. Earthquakes are not a new phenomenon, their effects are immediate and observable to those affected, and people generally know about their exposure to earthquake risks, based on the level of seismic activity at their location. Thus, earthquake hazards would appear to fall fairly low on the Unknown Risk scale in Fig. 2. Since earthquakes are perceived as somewhat uncontrollable, catastrophic, and involuntary, the location would fall to the right on the Dread Risk scale, placing it somewhere in the lower-right quadrant of the risk factor space. Fig. 3 shows an approximate location for the earthquake hazard based on the previous discussion. Fig. 3 is a repetition of the risk factor space in Fig. 2. Most of the data from Fig. 2 are left off of Fig. 3 for clarity, with the location of the terrorism hazard and the posited location of the earthquake hazard highlighted.

In PBD methods, risk perception factors can be taken into account explicitly through the appropriate definition of performance objectives. SEAOC instructs the designer and building developer to choose a performance objective based on “the building’s occupancy, the importance of functions occurring within the building, economic considerations including costs related to building damage repair and business interruption, and considerations of the potential importance of the building as a historic or cultural resource” (SEAOC 1995). Through this choice of the performance objective, the designer’s and developer’s own perceptions of earthquake risk and their understanding of the public’s perceptions of earthquake risk enter into the design. Many of the same considerations presented in Table 3 will influence the choice of performance objectives.

### Risk Perception in Fire Design

Fire safety designers have begun to take into account the public’s risk perceptions when developing and applying PBD methods for

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**Table 2. IBC Seismic Use Groups (Adapted from ICC 2000)**

<table>
<thead>
<tr>
<th>Category</th>
<th>Nature of occupancy</th>
<th>Example facilities</th>
<th>Seismic factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Anything not in II, III, or IV</td>
<td>Restaurant; Most retail shops; Single-family home.</td>
<td>1.00</td>
</tr>
<tr>
<td>II</td>
<td>Substantial hazard to human life in the event of failure</td>
<td>Schools or day cares with capacity &gt;250 people; areas of assembly for &gt;300 people; healthcare facilities with &gt;50 resident patients; jails; other occupancy with &gt;5,000 occupants; power generating facilities; water and wastewater treatment facilities; other public utilities.</td>
<td>1.25</td>
</tr>
<tr>
<td>III</td>
<td>Essential facilities</td>
<td>Hospitals; fire, rescue and police stations; earthquake, hurricane, or other emergency shelters; emergency preparedness facilities; structures containing highly toxic materials; aviation control towers; facilities with critical national defense functions.</td>
<td>1.50</td>
</tr>
<tr>
<td>IV</td>
<td>Low hazard to human life in event of failure</td>
<td>Agricultural facilities; minor storage facilities; temporary facilities.</td>
<td>1.00</td>
</tr>
</tbody>
</table>

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**Table 3. Relationship of Building Type to Dread Risk Factors**

<table>
<thead>
<tr>
<th>Building type</th>
<th>Psychometric risk factors</th>
<th>Category</th>
<th>Load factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schools</td>
<td>High risk to future generations; Catastrophic, involuntary</td>
<td>II</td>
<td>1.25</td>
</tr>
<tr>
<td>Assemblies</td>
<td>Catastrophic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Healthcare</td>
<td>Inequitable, involuntary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jails</td>
<td>Involuntary, inequitable, uncontrollable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occupancies with &gt;5,000</td>
<td>Catastrophic, uncontrollable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power, water, utilities</td>
<td>Catastrophic, inequitable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospitals</td>
<td>Involuntary, inequitable, uncontrollable</td>
<td>III</td>
<td>1.50</td>
</tr>
<tr>
<td>Emergency shelters</td>
<td>Involuntary, inequitable, uncontrollable, catastrophic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toxic storage</td>
<td>Fatal consequences, catastrophic, risk to future generations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Fig. 3.** Posited location of earthquake hazard in risk factor space
fire design, as “human values and perceptions influence the public mandate” to manage risks through regulation (Wolski et al. 2000). Thus, the building code must somehow take into account social perceptions of risk. Wolski et al. also argue that prescriptive fire safety codes implicitly take account of psychometric risk factors. As an example, an occupant of a single-family home is statistically more at risk from fire death by fire than an occupant of a high-rise apartment building, but highrises are subject to much stricter fire safety regulations. Wolski et al. explain that this is because society considers events involving many deaths in a single event, such as in a high-rise fire, catastrophic. Perceived control also enters into the equation, in that renters tend to be perceived as having less control over their fire safety than do homeowners, and are also at risk from neighbors who may not take the same level of precautions. The same could be argued for hotels, where a guest may be unfamiliar with the risks (or the surroundings), as opposed to single-family homes where occupants are well aware of most hazards and of effective egress routes.

PBD is based on quantification of performance levels, so risk perceptions must be quantified for use in building codes (Wolski et al. 2000). Wolski proposes using “risk conversion factors” (RCFs) for this purpose. These are developed by looking at historical values of “acceptable risk” at each end of the spectrum for the various psychometric factors (see Table 4). These RCFs could then be used to group buildings into safety classes in a step analogous to occupancy or use categories in prescriptive codes, and to determine appropriate safety factors for design. For example, from a probabilistic perspective, RCFs could be used to determine an appropriate value for a building’s maximum expected risk to life (Wolski et al. 2000).

The ICC Performance Code also utilizes these risk factors when specifying its use and occupancy classifications, as described in Table 5. Combining these use and occupancy factors with a facility’s importance to the community gives the facility’s Performance Group Classification.

### Terrorism-Resistant Design

Few building codes in the United States currently address terrorism-resistant design of buildings. Guidance documents, however, such as FEMA 426, Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings, along with a series of publications addressing security issues in private-sector buildings are being developed and published (FEMA 2003). Although not a new hazard, terrorist attacks have not, until recently, been seen as an important design load for most domestic, civilian buildings. Due to recent catastrophic attacks on civilian buildings, and speculation of more destructive and deadly attacks being planned, a methodology for designing buildings to resist these attacks must be made available to building designers, and PBD techniques appear to hold promise in this respect. In order to be useful, this methodology must include a multihazards approach to design. That is, the methodology must include design against a range of hazards including events such as earthquakes, fires, and terrorist attacks. Additionally, a terrorist attack is not necessarily a single type of event. To be truly effective at improving the safety of building occupants, a methodology must address the full range of terrorism-related threats, including not only traditional blast attacks, but chemical and biological agent attacks, and attacks on any system in the building. An illustration of the range of attacks that must be considered is given in Table 6.

#### PBD Applied to Design for Terrorist Attacks

The terrorism hazard is target dependent, unlike the earthquake hazard, which is location dependent. Thus, all buildings in a given area will experience approximately the same risk of occurrence of a given earthquake hazard, but different types of buildings in the same area will experience different risks of occurrence of a terrorist attack. Fire hazards are also target specific, in that buildings in the same location may have different characteristics, leading to differing vulnerabilities to fire hazards. The factors affecting hazard levels and occurrence probabilities can be addressed by PBD, to allow for incorporation of differing hazard levels and occurrence probabilities into design.

As terrorism represents a constantly changing design challenge, it seems unlikely that prescriptive code requirements will be fully effective in countering this hazard. Codes are not in-
tended to be static documents, but must evolve as new information becomes available or new situations arise. PBD is well suited for design issues that deal with evolving, “cutting-edge” concepts. PBD is also well-suited to use in a target-specific hazard environment, as appropriate performance objectives can be chosen according to the hazard level of individual buildings. Thus, PBD seems a natural approach for development of an adaptable terrorism-resistant design methodology.

### Risk Perception of Terrorist Attacks

The terrorism hazard possesses all of the components of a dread risk. Terrorism is essentially uncontrollable. An attack could theoretically happen anywhere, anytime, to anyone. As the time, place, and target of an attack are the choice of the attacker, terrorism represents an involuntary risk, and since the effect of an attack would depend primarily on proximity to the attack, rather than the demographics of the victims, it can also be characterized as having inequitably consequences. The consequences can be far reaching, catastrophic, and fatal. Finally, based on the amount of money and effort spent in recent years to deter terrorist attacks, the feeling that we as defenders “have to be right every time,” whereas the attackers “only have to be right once” (Hudson 2004), and the fact that terrorism is not likely to vanish in the near future (Dowling 2004), indicate that the risk of terrorism is not easily reducible, and will continue to affect future generations. In fact, Slovic et al. (2004) present terrorism as falling high on the dread scale (see Fig. 3). Relatively recent, extremely vivid images of terrorism are also readily available in the public memory. Because of this mental availability, dread, and the potential for catastrophic consequences, it appears that the public is indeed anxious about the risk of terrorist attacks. See, e.g., Bruder (2003), Gertner (2003), Kilman et al. (2001), Kirkpatrick (2002), McCarthy (2001), Shear (2002), and Zhao (2001).

Attempts have been made to use quantitative risk analysis to address terrorism risks (Garrick 2002). The classical definition of risk is given as (King et al. 2003)

$$\text{Risk} = p(\text{Occurrence}) \times (\text{Consequence}|\text{Occurrence})$$

In words, risk is the probability of occurrence multiplied by the magnitude of the consequences, given that the event occurs. This definition represents the expected consequences of a terrorist attack over the time period being evaluated. This is an adequate characterization for finding an average risk over time. However, for uncommon events with small probabilities and large consequences (like terrorist attacks) this type of analysis may not be adequate to characterize the risk, nor to describe the public’s perception of it (Clemen and Reilly 2001).

Sjöberg states that while the rational way for society to allocate resources would be a system that makes all risks equal, in reality the public’s opinion of consequences is more important than the probability of occurrence in terms of setting priorities for risk policy (Sjöberg 2001). This tendency to weight consequences more heavily than their probability of occurrence is known as probability neglect, and is discussed in relation to terrorism by Sunstein (2003). With this in mind, it seems prudent to design buildings to minimize potentially catastrophic consequences, even though risk management based on strictly rational allocations of resources and the classical definition of risk might not reach the same conclusion. Slovic also argues that experiential thinking utilizing both feelings and analysis is needed to address the terrorism hazard (Slovic 2002). He cites the concepts of “risk as feeling” and “accidents as signals” as possible explanations for why terrorist attacks weigh more heavily on the minds of the public than they would be expected to based on the classical definition of risk (Slovic 2002).

### Path Forward

Work has begun on developing PBD methodologies for blast-resistant design (Whittaker et al. 2003). However, there is much to be done before PBD can be adopted for protection against blast, and more generally, against terrorist attacks. In particular, in addition to structural performance for blast, impact, and fire loads, terrorism-resistant design will need to address all aspects of a building’s design, including systems such as mechanical (air handling), electrical, plumbing (water supply and fire protection), and telecommunications systems. A first step will be to characterize the types of terrorism-related hazards facing building designers.

Once hazards have been characterized, terrorism design levels must be developed. This will involve a determination of tolerable levels of damage, or “acceptable” risk to facilities. The public is often unwilling or unable to quantify acceptable risk, so building designs and codes will need to incorporate such judgments (Sevin and Little 1998). The next step will be to quantify performance levels in the event of a terrorist attack. These will need to be wide ranging and broad based in order to encompass multiple threats, such as those listed in Table 6. This implies the need for a risk management strategy to determine the point at which the costs of terrorism-resistant design become prohibitive, as well as which buildings need to be designed to levels exceeding prescriptive requirements. This is an issue of acceptable risk. Performance

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### Table 6. Terrorism-Related Hazards for Buildings

<table>
<thead>
<tr>
<th>System</th>
<th>Potential hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural systems</td>
<td>Blasts, projectiles, impact, other attacks on load-bearing members (e.g., cutting columns, knocking down load-bearing walls)</td>
</tr>
<tr>
<td>Fire suppression</td>
<td>Arson, fire as secondary effect to blast</td>
</tr>
<tr>
<td>Mechanical systems</td>
<td>Dispersal of toxic substances through air-handling systems, attacks on elevators</td>
</tr>
<tr>
<td>Electrical systems</td>
<td>Disruption of power distribution, power surges</td>
</tr>
<tr>
<td>Plumbing systems</td>
<td>Dispersal of toxic substances through potable water supply, attacks on fire-suppression equipment</td>
</tr>
<tr>
<td>“Transport” systems</td>
<td>Attacks against stairs, elevators, parking areas, etc.; attacks that slow or retard egress in the event of an evacuation</td>
</tr>
<tr>
<td>Communications systems</td>
<td>Disruption of communication systems</td>
</tr>
<tr>
<td>Personnel</td>
<td>Direct attacks on occupants (e.g., with firearms)</td>
</tr>
<tr>
<td>Computer networks</td>
<td>Cyberattacks such as viruses, physical attacks on servers, etc.</td>
</tr>
</tbody>
</table>
objectives could then be constructed from the design levels and performance levels.

In order for any PBD method to be useful, it is absolutely vital that accurate, useful simulation and modeling techniques for the performance of building systems be developed and integrated such that the overall performance of buildings can be predicted. Data collection and reporting to support simulation assumptions and to verify actual performance may also be necessary for the full implementation of a performance-based building design process. Any PBD methodology used to design terrorism-resistant buildings must also integrate the diverse engineering fields that contribute to the design of the various systems in a building.

In April 2005, the ICC stated its intent to address building safety and fire prevention code issues raised by findings from the World Trade Center collapse (Gibson 2005). However, competing viewpoints remain in the engineering profession as to whether design criteria for abnormal loadings such as terrorist attacks should remain voluntary, or building code provisions should explicitly address such extreme loading events (Post 2005). PBD methods could be required for certain categories of “high-risk” buildings, which would then need to be defined. In this case, the method would be optional for buildings not considered “high risk.” Alternatively, a large range of performance objectives could be created, from which an appropriate objective could be chosen based on facility type. Finally, PBD methods could be available and optional for all buildings, as is currently the case in many fire and mechanical systems design standards.

This disagreement over the best course of action indicates that performance-based codes will not completely replace prescriptive codes. In fact, a prescriptive solution is often used as a baseline in PBD, and prescriptive solutions would most likely continue to be used for the majority of buildings, even with the advent of PBD methods for terrorism-resistant design. However, to address new and dangerous hazards to certain buildings, it is important that creativity in design processes and methods be encouraged now to support PBD for terrorism-resistant building designs.

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