

BUILDING REGULATORY SYSTEMS IN A POST-SEPTEMBER 11 WORLD

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INTRODUCTION

The September 11, 2001 attacks in the United States have initiated a significant discussion and rethinking among building regulators not only in the U.S., but also around the world. While most quickly state that regulations should not require that buildings be designed to resist impact by fully loaded aircraft, there is an active dialog on what have come to be called *extreme events*. Much of the discussion in the literature has focused on technical issues like structural fire resistance and progressive collapse, but there is a public policy debate that should precede and drive the engineering and design discussions. The purpose of this paper is to lay out some of these issues, such as expected response to extreme events; “target” buildings; standards of practice, qualifications, and ethics; regulation of existing buildings; management of risk; and others, and to hopefully start that policy debate.

INTENT OF BUILDING REGULATIONS

A safe and efficient built environment is crucial to any society; so building regulations have evolved to reflect societal expectations for public buildings. Most regulations address the health, safety, and welfare of building occupants and may include other societal goals such as resource conservation, historic or cultural preservation, and protection of economic value.

The safety goal has historically meant protection against unreasonable risk of injury in the normal use of the buildings (e.g., slips and falls), and safety of occupants and firefighters in case of fire.

Prescriptive Regulation

Traditionally, building regulations have been prescriptive in form. For example, stair geometry and handrail dimensions are specified based on research and experience as to what results in the least incidence of trips and falls. Building use categories have evolved as surrogates for variations in combustible loads, fire sources and occupant characteristics that affect the risks from accidental fires. The same use categories are also used to specify characteristic live loads for structural design.

One fire related risk that traditionally has not been addressed in building regulations is arson. This is considered an intentional, criminal act that is relegated to law enforcement and security practice, and an arsonist could easily circumvent any measures taken in building regulation to limit damage to the building. Arson is mentioned here because there are interesting parallels to terrorism that will be discussed later.

Performance Regulation

In recent years there has been a transition in many countries to performance regulation. Here the regulation specifies required outcomes and the methods used to achieve these are left to the owner and designer. Performance regulations are seen to result in lower cost, better functioning buildings by facilitating innovative solutions, especially for buildings that are unique or constrained.

The move to performance regulation initiated a long-overdue dialog on the real intent of building regulations. One country questioned whether it was appropriate for society to require a building owner to install and maintain systems intended only to protect his own property, or whether this was a private matter between him and his insurer. Another country pondered the extent to which building regulations should address protection of firefighters who are professionals trained and equipped to deal with the risks of fire. Each of these and others enjoyed spirited debate and were appropriately resolved as public policy issues within their own process of regulatory development.

Similarly, performance regulations explicitly address design loads or criteria that are often recommended by technical experts and vetted as public policy through a due diligence process. Wind, snow, and seismic loads are specified by location based on historical records of magnitude and return frequency and a policy decision that reflects society's risk tolerance.

One of the primary advantages of performance-based regulatory systems is the additional flexibility afforded to designers to address functionality, sustainability, aesthetics, and historical preservation issues that have been difficult in prescriptive environments. Performance systems have been characterized as a more collaborative atmosphere in which owners, designers, and regulators work together toward common goals.

Extreme Events

Extreme events can be defined as any event or load that exceeds the design event which is usually the worst likely over the life of the building. While there is general agreement that it is inappropriate to regulate to extreme events, this does not mean that extreme events can be ignored. Regulators need to understand the risk of extreme events – in other words, to balance the severity of the consequences with the likelihood in the context of their society's risk tolerance.

Following the September 11 attack it was quickly pointed out that the initiating events far exceeded any design criteria applied to the buildings. Historically, buildings are not designed to resist tornados because the design wind speeds would far exceed practical limits for the tiny probability that any specific building might be struck. Most designers and regulators agree that the same approach is valid for terrorism with the possible exception of what have been called *signature* (or *target*) buildings, and there the decision should rest with the owner. While this would most often involve government buildings and headquarters of high-profile companies, building owners may wish to consider the risks to their business should the building be rendered unusable for a period of time.

PUBLIC POLICY

Societal Expectations

Building regulations reflect society's expectations for the built environment as a matter of public policy. Policy makers, generally those empowered to make laws in the society, have the job of interpreting those expectations in the context of the costs (economic or intrusive) society is willing to bear. The best example is the low level of regulation of individual residential construction. While a primary objective of building regulations is to provide public safety from fire, and the vast majority of fire deaths occur in home fires, most societies will not accept regulatory intrusion into individual homes ("A man's home is his castle"). A higher level of regulation is applied to multi-family housing because society is less willing to accept the risk of death, injury, or economic loss from a neighbor's fire.

Where things get exciting for policy makers is when society's expectations change. Prior to September 11, 2001, public expectations for protection against terrorist attack in most countries were low. Even in Northern Ireland and England where bombings were frequent, the only impacts were vigilance and removal of public trash containers. The impact of the 2001 World Trade Center attacks has initially led to the general focus on homeland security but as yet has not had significant impact on building regulations. The homeland security dialog has raised issues about chemical, biological, and nuclear threats that have not occurred but which may have more impact on building design than the WTC incident.

Due Diligence

The level of regulation imposed on buildings is a matter of public policy that must be determined by policy makers following a process of *due diligence*. This follows from the principle that those regulated must be consulted and informed about regulations to which they will be subject. Thus building regulations are debated in public, including public hearings, with opportunities to provide written or oral comments that are required to be resolved. Regulations must be established by those empowered to make laws or their agents, and that power cannot be delegated. Regulations must be accessible for public review.

Minimum Performance Levels

The role of the technical community is limited to the determination of what levels of performance are possible and the costs associated with each, so that the policy makers can decide on the minimum performance required and the cost society is willing to bear. In prescriptive regulatory systems this role is clouded because the correspondence between the specification of building features and the intended result is generally not stated explicitly. In performance regulation, the specific solutions are not part of the regulation and the specified performance levels are public policy.

Target Buildings

Certain buildings are more likely to be targets of terrorist activities, although the Murrah building in Oklahoma City would likely have been far down any such list. These generally tend to be government buildings or signature buildings housing high profile companies. Thus far, the public policy position has been that security levels

at such buildings are not dictated in the regulations but rather are decided by the owners in consultation with their insurers. For example, following the bombings in Africa the U.S. Department of State established guidelines for embassy buildings that included security perimeters and blast resistant windows. Most large corporations have put broad ranging security policies in place, but regulation as a matter of public policy is considered unlikely.

DESIGN PROFESSIONS

Building construction is a highly regulated industry in most countries. Design professionals work with owners and regulators to produce functional buildings that meet both the needs of their owners and the expectations of society. Design professionals are normally qualified by examination and licensed, the maintenance of which increasingly requires formal, continuing education. Licensing requirements further provide a mechanism for enforcement of professional ethics and standards of practice by licensing review boards with the authority to investigate complaints and to revoke licenses.

Standards of Practice

Building regulatory systems depend heavily on standards to provide underlying technical details. One broad class of such is standards of practice. Often these are standards developed and maintained by engineering societies as guidance to their discipline and to the regulators overseeing the system.

Standards of practice are even more important in performance-based regulatory systems where they document accepted methods for evaluating performance against the regulatory objectives. Regulators need assurances that the methods used by the designers are appropriate (generally accepted in the profession) and accurately predict performance.

An example is the use by Structural Engineers of the *limit state design* methodology. Here the loads to be carried by each structural element are determined from design loads (live, wind, snow, seismic, ...) and classical engineering mechanics analysis. In the U.S. the design loads for buildings are established by the American Society of Civil Engineers (ASCE) in their Standard ASCE 7¹, which is a mandatory reference in the building codes.

The practice of fire safety engineering is still in the process of establishing its standards of practice, through organizations such as the Society of Fire Protection Engineers (SFPE) and the International Organization for Standardization, particularly ISO TC92 SC4. Analytical methods, generally using numerical simulation models, are becoming generally accepted, but work is ongoing on the selection of design fires (analogous to the design loads in ASCE 7) and on estimates of uncertainty from which would come agreed safety factors.

Safety Factors and Uncertainty

Building design and regulatory systems depend on safety factors to account for uncertainty (variability) in actual construction. Although it could be argued that what constitutes an adequate safety factor is a public policy decision, they are usually established by the design professions as a standard of practice.

In limit state design, structural element loads are increased by an agreed safety factor that represents the uncertainty in the load estimate. Also, element (material) strengths are decreased by another agreed safety factor that represents the uncertainty in the actual strength. Since there are significant cost implications for larger safety factors there is pressure on the test method developers and manufacturers to reduce uncertainty and decrease safety factors.

There are, however, complications in fire safety engineering not encountered in other disciplines. In structural design, increasing the load is always a worse case but this is not necessarily true for fire. Larger fires may be self-limiting (ventilation controlled) or may be more effectively mitigated by protection systems (e.g., sprinklers), so the worst threat may be posed by some intermediate fire size. Further, the highest losses in fires tend to be associated with multiple (sequential) failures, any one of which would not present a problem. Thus, in fire design it may be more appropriate to consider large numbers of scenarios with uncertainties applied to individual components and all combinations analyzed to identify the most risk-significant. These would then become the design scenarios against which the performance of the building would be judged.

Qualifications and Ethics

Regulatory requirements for licensure of design professionals establish minimum qualifications for those who design or review the design of public buildings and facilitate a system under which complaints can be investigated and licenses suspended or revoked for violations of regulations, standards of practice, or ethics. Licensed (Chartered in some countries) engineers are typically bound by professional ethics to limit their practice to areas of competence.

Regulatory requirements for independent certification of qualifications in the building industries (including construction trades) have increased substantially as a result of ISO9000 type quality programs and in response to studies that show a large fraction of construction problems are the direct result of work performed by unqualified parties. Some countries (Japan, Spain) have instituted mandatory warranty programs for residential construction that have caused the insurers providing the coverage to organize programs for independent certification.

NEW APPROACHES TO REGULATION

The transition to performance-based regulation is having a profound effect on the overall regulatory system. Two international groups have been organized to explore and develop many of these issues. One, the Interjurisdictional Regulatory Collaboration Committee (IRCC) is made up of the head regulatory official (responsible for the development and enforcement of building regulations) from each member country in which performance-based regulations are in place or under development (see <http://www.ircc.gov.au/>). IRCC was formed to provide a forum for the exchange of information among peers. The second is the International Council for Research and Innovation in Building and Construction (CIB) Task Group 37 on Performance-Based Regulatory Systems which is chartered to conduct needed research on a broad range of topics in support of such regulation.

Cradle-to-grave Regulation

In prescriptive regulation it has been assumed that there is only one level of performance needed by buildings within any single use category – that being what is provided by the prescribed requirements. Challenges to this one-size-fits-all philosophy were the impetus for performance regulation in many areas.

Under this system the only time the design needs to be re-evaluated is if the use category changes, as long as the existing systems are maintained. New buildings are inspected against the regulations and need no further verification unless significantly renovated or the use category changes.

In performance systems building performance is matched to the specific needs of the design and if any aspect of that design that affects assumptions or criteria change the design must be re-evaluated. In the ICC Performance Code² these assumptions and design criteria are called *bounding conditions* and any change to a bounding condition that results in a change in risk triggers a new performance evaluation. Thus regulation under the building code applies over the entire life of the building (cradle-to-grave). This required some new regulatory approaches, such as the performance analysis being filed as a deed restriction and the creation of a renewable certificate of compliance (first used in the New Zealand performance – based regulations).

Existing Buildings

A similar issue is the regulation of existing buildings and the retroactive application of regulatory changes other than when the building use changes. When prescriptive regulation was the norm, existing buildings were not regulated beyond maintenance of required systems and features unless the authorities could prove that the condition of the building represented an imminent hazard to life. Changes to prescriptive requirements were seldom retroactive since building owners objected to changes in regulations imposing significant costs. Primary exceptions in the U.S. have been retroactive requirements for smoke alarms in occupancies where people sleep and for the retrofit of fire sprinklers in high-rise buildings.

The NFPA's Life Safety Code³ has long included minimum life safety requirements for existing buildings that are generally lower than those applied to new construction. The problem has been that it is difficult to enforce these requirements since most jurisdictions do not inspect or regulate buildings unless changes are made. This led to the approach contained in the International Existing Buildings Code⁴ in which upgrades are required when significant (explicitly defined) repairs, alterations, or additions are made. This code also deals explicitly with historic buildings and their upgrade to modern structural and life safety requirements while maintaining their historical fabric.

As performance regulations became more common, it was clear that there were two levels of (minimum) performance and two levels of risk exposure. Most regulators feel that the public does not expect to be subjected to increased risk in older buildings. This has led to new interest in the development of regulations for existing buildings that attempt to reach equivalent levels of risk.

Risk management

Risk has long been recognized as the best metric for building regulation, because society is basically risk averse. Buildings are required to be designed to limit damage from hurricanes based on historical data on coastal locations where hurricanes have struck, and their strengths. Buildings are not designed to resist tornados because, while the impacts on a given building would be higher, the likelihood of any particular building being struck is much lower.

Risk concepts have been incorporated into many of the performance-based regulatory systems developed in recent years. The ICC Performance Code for Buildings and Facilities includes risk management criteria as the basis for required building performance. The NFPA Building Construction and Safety Code⁵ incorporates risk concepts into its design scenarios by examining the increased consequences of failure of primary mitigation strategies and balancing that against their reliability.

Enforcement through Third Parties

The higher technical sophistication of performance-based regulation can represent a challenge to some regulatory organizations, particularly in smaller jurisdictions. This has led to the recognition of third party regulatory enforcement where regulatory reviews are performed by specialists on behalf of the regulators. One way this is done is to require the submitter to pay for experts or peer reviewers acting as advisors to the regulator. Another is for registered reviewers to be delegated the authority to decide if a design complies with the regulation. The choice of methods rests largely with the legal ability of regulators to delegate their responsibilities.

Owner responsibilities

Because the staff and resources to reinspect existing buildings are often limited, owners are increasingly being made responsible to maintain systems and to exercise controls over their buildings based on liability for legal actions rather than by direct enforcement by regulators. In some cases documentation is required from the owner and failure to submit such can result in withdrawal of permission to occupy the building. In other cases, non-compliant owners simply assume additional liability should a fire occur.

EMERGING ISSUES

The September 11 attacks precipitated a global concern about what has become known as homeland security. Policy makers are asking regulators what needs to be done to address societal fears of terrorism, be it global or local. Questions include whether the list of threats currently regulated against should be expanded and what vulnerabilities exist to a broad range of extreme events, including chemical, biological, and radiological (CBR) threats.

Prediction of Structural Fire Performance

One of the issues coming directly from the WTC attack is the need to understand the structural performance of buildings over a broad range of fire exposures up to and including extreme events, which all agree exceed the practical limits of regulation. Most regulators agree that the first ever fire-induced structural collapse of steel-frame high-rise buildings in New York represented a wake up call. Society is willing

to accept the devastation of such buildings such that they must be demolished (e.g., Meridian Plaza) but they must not collapse unless the initiating event is immense. Interestingly, some feel that the collapse of the towers was understandable in light of the aircraft impact, but the total collapse of WTC 7 and partial collapse of 3 and 5 were not.

Integrated analytical methods

Many of the pieces needed to predict structural performance for arbitrary fires are in place but need to be integrated into a complete analysis. Detailed computational models of fire in buildings are in use for design and regulation. Heat transfer models (so-called finite element models) that are capable of predicting the time and spatially varying temperatures in structural members to sufficient accuracy also exist and are in common use.

What is currently missing is the ability of these models to work together, and joining them involves some significant, technical issues. Further, data on the physical properties of many structural materials at elevated temperatures is lacking. Finally, some important details such as phenomena leading to torsion of members, the performance of connections, and the interaction of some major structural systems are not well understood⁶. All of these can be addressed in time and the time needed would be shortened if more people can work together on the solutions.

Fire as a Building Load

Structural engineers design buildings to resist certain loads and load combinations, and it has been suggested that fire should be treated as another load if design fires could be described in the appropriate manner. However there are several problems with this approach.

Fire is an event like an earthquake or hurricane, but where these natural events have statistical distributions in time (magnitude and return frequency), fires are unique because nearly all fires start small and grow until they run out of fuel or air or are extinguished. Large fires are generally the result of many things going wrong simultaneously, and thus represent a string of conditional probabilities that are not well described in normal terms.

One suggestion for how to develop design fire specifications specific to a building space to result in the same stress on that space has been proposed⁷ but this does not address the issue of return frequency.

Passive and active protection

The past decade has seen a significant shift in fire protection philosophy from passive protection (compartmentation) to active protection (fire sprinklers) because of the latter's better performance for life safety. The September 11 events have raised questions about this approach because the initiating event rendered the active systems inoperable but also compromised the passive protection of the egress system in the area of impact.

Trade-offs

The result of this experience is for trade-offs in the regulations that reduced passive protection when active systems are provided to be re-examined. These trade-offs were granted at least partially because of the very high reliability of fire sprinklers in typical events. The observed failure was caused by the extreme nature of this event but raises the issue of society's tolerance of a high consequence, low probability event. Sprinkler trade-offs are the current subject of study in the U.K. by a special committee of BS 9999 and are being questioned in a recent report from the National Association of State Fire Marshals⁸.

Robustness

A parallel issue is the aforementioned failure of the egress system in the area of impact trapping occupants above the impact zone. There is also the issue of the ability of the spray applied fireproofing to remain under the severe impact loads experienced. Again this is a question of society's tolerance of a high consequence, low probability event.

Reliability

In a broader context the issue to be resolved is the ways in which reliability of mitigation strategies are accounted in the overall performance of the system and the degree to which single failures are prevented from resulting in unacceptable consequences.

Progressive collapse

One of the most significant issues to come from the September 11 attacks is the debate on progressive collapse. In the U.S. building regulations the issue is addressed by a requirement that any structural collapse not be "disproportionate to the initiating event." An often-cited example (including in ASCE7-02) of the type of disproportionate collapse to be avoided is the 1968 Ronan Point disaster in which a gas explosion in a 22-story apartment building in England blew out a wall leading to the collapse of an entire corner of the building. A newer example is the collapse of the Alfred P. Murrah building in 1995 after a truck containing a 4000-pound fertilizer bomb exploded near the 9-story reinforced concrete building.

The debate in the regulatory community relates to what is disproportionate. The important policy decision is where to draw the line between design levels and extreme events. An issue to be addressed by the policy makers is to quantify the performance demanded by society. Some in the technical community have said that the collapse of WTC 1 and 2 were not disproportionate to the initiating event. Some critics say that the buildings should have stood until all occupants and responders could be evacuated.

Egress vs. relocation

Current building regulations incorporate protected routes for emergency egress of occupants in case of fires. As a result of the September 11 events the security paradigm shifted to Homeland Security and the response to a much broader range of possible threats.

Clearly, egress is no longer the only appropriate response – in some threats, building occupants need to be kept inside (in so-called lock down), and in other cases occupants might be moved to the upper parts of buildings away from street level threats. These responses place additional burdens on the building and especially the communication of information and directions to elicit the desired response. Occupant training is another large issue. Current technology for emergency voice communication as part of the fire alarm system provides some capability for instruction. The discussion among the technical experts is that the degree of flexibility in response needed may require the ability to provide more detailed information in textual form, such as by display panels or pop-up windows on everyone's computer screens.

As regulators consider moving occupants within the building for conditions other than fire, and the possible need to increase egress capacity for tall buildings in fire if occupants are unwilling to await phased evacuation, there is growing interest in technologies for protected elevators. The global elevator industry is looking at research conducted more than a decade ago and at new approaches to address shortcomings in systems reliability⁹.

CBR threats

The newest threats being considered under the Homeland Security theme are chemical, biological, and radiological (or CBR) threats. These may have some direct impacts on building design and code requirements such as the location of fresh air inlets and the ability to go to total recirculation, but it is unlikely that more significant (and costly) changes in minimum building regulations would be adopted while the threat remains remote.

NEEDS OF BUILDING REGULATORS

Building regulators face a daunting task to sort through all of the emerging issues and to make policy decisions on what society desires before many of the issues can be fully discussed in public forums. What the regulators need most from the technical community is a clear description of what technology offers with respect to the performance of buildings under this broad range of conditions and the costs and trade-offs associated with these technologies.

The structural engineering profession is in reasonably good shape. They can assess the expected response to static and dynamic loads in various combinations and have reasonable estimates of the uncertainty and statistical distribution of those loads over time. They have methods to measure the properties of materials (at least at room temperature) and the uncertainty and variability of those properties in actual materials. Some issues need to be debated, for example lateral members designed to be strong enough to transfer loads from a failed column may enlarge a collapse zone by pulling on adjacent members.

From fire safety engineering, the regulators need the ability to predict to a known uncertainty, the structural performance to a broad range of fire exposures including extreme events. These methods need to replicate both the time to and the mode of, failure. Engineering methods need to quantify uncertainty generally, and the impacts of expected distributions in input parameters and/or the sensitivity of results

to these. To this end, calculation methods and models need to directly support uncertainty analysis and distributed inputs.

Human factors research is needed to determine the combinations of systems and training necessary to obtain the desired response of building occupants to the range of situations expected and for which the building is designed. This work also needs to quantify the time needed for these actions to be completed and the expected variability.

Finally, the regulators need the policy makers to decide what threats need to be designed against and which are considered extreme events. For the latter, there needs to be some understanding of the consequences that would be tolerated as long as the probability is sufficiently low.

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