IDENTIFYING AND REGULATING FOR MULTIPLE LEVELS OF PERFORMANCE

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ABSTRACT

Building regulations are legal instruments intended to ensure that buildings perform in such a way so as to provide essentially equivalent, socially acceptable levels of health, safety, welfare and amenity for building occupants and for the community in which the building is located. This is typically accomplished through regulatory controls on the design, construction and operation of buildings, covering such diverse areas as structural stability, fire safety, lighting, ventilation, plumbing and sanitary facilities.

In a traditional, prescriptive-based regulatory system, the performance objectives are often embodied in specific requirements that vary by building use or occupancy type. Such requirements may be manifest as resistance to loads, construction types, fire resistance ratings, travel distances, pedestrian circulation aids, ventilation rates, and potable and waste water specifications. Based on the collective knowledge, experience and desires of regulatory developers and interested and affected parties, minimum requirements are established for all buildings within each use or occupancy groups.

In many performance-based regulatory systems, however, differences between building uses and occupancy types are not so clearly delineated, at least in terms of regulatory requirements. As a result, many of the decisions regarding the “adequacy” or “appropriateness” of the building and systems performance are left to the design team and to the local code authorities. Thus, similar buildings constructed using the same regulations may perform dissimilarly, and because the acceptability of building performance depends on such factors as the use of the building and the users of the building, the social acceptability of the building performance may be unclear.

One way to address the various and varied building performance requirements in a performance-based building regulatory system is to introduce the concept of *multiple levels of performance*. In brief, the establishment of multiple performance levels will help to provide uniformity in building performance, based on the use of buildings and the characteristics of the building users, without prescribing specific requirements. For performance under various hazard conditions, this can be accomplished by identifying risk and importance factors common to different building uses, and by defining associated performance requirements and design loads against which to test the expected performance. Although such an approach does not prescribe how the performance is to be attained, it provides different benchmarks for such diverse building uses as storage sheds, manufacturing facilities and hospitals. It also provides a mechanism by which to evaluate the performance of existing structures and to guide changes to existing structures that may be needed to attain a desired level of performance.

This paper outlines the concepts of risk, hazard and importance factors, performance groups, multiple levels of performance, and magnitudes of design loads, with a focus on identifying and describing levels of tolerable building performance, for different buildings, under various magnitudes of design loads.

KEYWORDS:

Performance-based building regulations; public expectations; performance levels.

INTRODUCTION

Many countries around the world have either introduced performance-based building regulations or are in the process of doing so (see, for example, CIB TG11, 1997; Meacham, 1998; IRCC; 1998). Rationale for introducing performance regulation ranges from downsizing of government, deregulation, and facilitation of trade, to increased design flexibility and reduction in unnecessary costs. Specific rationale notwithstanding, one observable result in many transitions to performance regulations is the significant reduction in the text of the regulation (or code). It is often argued that this reduction in volume is a result of a focus on performance goals, objectives, and requirements rather than on the prescription of specific design and construction features.

However, as the structural nature of building regulation and its content changes, and text is significantly reduced, care must be taken to ensure that the central aim of providing socially and culturally tolerable levels of safety for the persons that occupy buildings is not diminished. Central to this concern, and to the performance issue overall, is adequately addressing societal expectations and requirements for the performance of buildings. To address this issue, one must first consider whether all buildings are required to perform in the same manner, and what metrics should be used to assess, evaluate, and/or predict performance.

PERFORMANCE EXPECTATIONS

Addressing expectations of the public in the development of regulation is essential, particularly in a democratic system. The negative impact of ignoring or inadequately addressing public concerns and expectations, for example, has been experienced in such areas as nuclear power and environmental regulation (Stern and Fineberg, 1996; Kasperson and Stallen, 1991; Fiorino, 1990; Pollack, 1985; Freudenburg, 1988; Slovic, 1987; Flynn et al., 1995). The negative impact of ignoring or inadequately addressing public concerns and expectations has also been experienced in building regulation (Meacham, 1999). This can be illustrated by example.

In the United States, building codes are intended to provide a minimum level of health, safety and welfare to the public, with a majority of the code provisions (e.g., fire and seismic protection) focusing on safety to life. When the 1994 Northridge, California, USA, earthquake occurred, many of the newer buildings had been constructed to the code-required “life safety” level of performance, i.e., the structure can sustain considerable damage as long as the occupants can get out safely. This helped save lives, but did little to minimize property loss and business interruption. As a result, although there were relatively few deaths (58), somewhere in the range of 80,000 to 125,000 people were temporarily or permanently displaced because of damage to their homes or apartments, with hundreds of millions of dollars worth of damage (NIST, 1994).

In general, the seismic engineers viewed the relatively low life loss as a success, whereas homeowners and tenants were left asking why their homes could not be lived in again without extensive rehabilitation, if at all. Likewise, many businesses did not understand why code-complying buildings were unusable after the event. In this case, what the code provided as a minimum level of performance was not what the public expected as a minimum level of performance. Not surprisingly, post-event analysis suggested this issue be addressed in future seismic regulation. As noted in one post-earthquake report, “the question of how much protection to provide is not one for engineers to answer alone” (NIST, 1994).

Unfortunately, the above situation is not unique, and similar divergence between ‘expected performance’ and ‘observed performance’ has been seen in the wake of other hazard events, including fires, floods, hurricanes, and tornadoes. If divergent views on expected performance continue to exist within performance-based codes, there is a chance that significant ‘unacceptable’ or ‘intolerable’ losses may result, when the aim is to avoid such losses by designing and constructing better performing buildings. This is especially true for codes that rely on users (often engineers alone) to define what is 'appropriate to the hazard' and 'suitable in the circumstances,' and provide little guidance on quantitative performance expectations for the building.

To address this concern, it would be useful for regulatory developers to have some means to assist them in assessing the levels of safety, health, access, amenity, community welfare, and property protection that the public expects, and for clearly identifying performance targets in resulting regulation. Such a process would encourage input from interested and affected parties, and would utilize broadly-accepted concepts, metrics, tools and methods in analytical areas. However, such a goal can be difficult to achieve. First, understanding public expectations and securing public involvement is not always easy, especially in more closed regulatory systems that have no clearly defined public input mechanisms (Meacham, 1999). Furthermore, it is extremely difficult to find a metric (or set of metrics) that can be agreed as appropriate indicators of performance and that can be applied to an entire building. Although not without problems, one metric that has the potential to fulfil this need is risk.

RISK AS A PERFORMANCE METRIC

Risk is a complex construct that means different things to different people. For some it is an indication of impending doom (e.g., risk of death), whereas for other it reflects the possibility for significant gains (risking a small investment in the stock market for the possibility of a large return). Likewise, some see risk as readily quantifiable given objective data (e.g., frequency times consequence), whereas others tend to view risk more qualitatively due to their concerns over the quantification of frequencies and consequences.

Although real differences exist in how people view risk, the negative connotation is often the most prevalent. Further to this view, most people agree in concept that risk can be defined as the possibility of an unwanted outcome in an uncertain situation. Difficulties most often arise when addressing the issue of the 'possibility of an unwanted outcome.' As used here, the possibility of the unwanted outcome is a function of three factors: loss of or harm to something that is valued, the event or hazard that may occasion the loss or harm, and a judgement about the likelihood that the loss or harm will occur (Meacham, 2000).

If interested and affected stakeholders (including scientists, engineers, public officials and the public) can agree to the concept of risk as described above, risk has the potential to be a performance metric for building regulation. This is so because one can readily define the unwanted outcomes in terms of that which can be damaged or harmed and the events and hazards that can result in those unwanted outcomes. Although more difficult, one can also obtain judgements on the likelihood that the unwanted outcomes will occur. One of the best ways to develop risk metrics, which gain the acceptance of a broad cross-section of interested and affected stakeholders, is through the process of risk characterization.

Risk Characterization

At one time, risk characterization was described as being the result of a risk assessment (NRC, 1983). However, more current thinking considers risk characterization as being the product of an analytic-deliberative decision-making process, wherein there is an appropriate mix of scientific information (from "traditional" risk assessment) and input from interested and affected parties throughout the process (Stern and Fineberg, 1996). In this paradigm, risk characterization is described as a decision-driven activity, directed toward informing choices and solving problems. It suggests that coping with a risk situation requires a broad understanding of the relevant losses, harms, or consequences to the interested or affected parties, and that risk characterization is the outcome of an analytic-deliberative process. These factors are important, for a number of reasons. For example, a singularly-focused view of risk may inadvertently miss important considerations, such as technical, social, economic, value, perceptual or ethical impacts. As a result, the problem may be formulated improperly, either technically, socially or in some other manner, and the resulting analysis may omit key parameters. In addition, if not all interested or affected parties are involved in the process, they may disagree with anything from the problem statement to the measure of risk selected. Sensitive populations may be left out, socio-economic factors may be ignored, or cultural sensitivities may be unknown.

The success of the risk characterization process depends critically on systematic analysis that is appropriate to the problem, responds to the needs of the interested and affected parties, and treats uncertainties of importance to the decision problem in a comprehensible way. Success also depends on deliberations that formulate the decision problem, guide analysis to improve decision participants' understanding, seek the meaning of analytic findings and uncertainties, and improve the ability of interested and affected parties to participate effectively in the risk decision process. In other words, good risk characterization requires a well-defined problem that those involved agree with, a sound scientific base, the proper use of analytical techniques with proper consideration of uncertainties and unknowns, and sufficient discussion and deliberation so that everyone understands all of the issues. The process will likely require several iterations, as new information and data become available, and as participants gain better understanding and raise more issues. It needs to be an interactive process, and not one where one group dominates the deliberations and/or analysis and forces a solution.

It is also very important that the process have an appropriately diverse participation or representation of the spectrum of interested and affected parties, of decision-makers, and of specialists in appropriate areas of science, engineering and risk analysis at each step. As intimated above, if not all of the right people are involved, there may be problems in characterizing appropriately, valuing properly and gaining acceptance of the outcomes at the end of the process. The more widespread the participation, and the broader the scope of factors considered at the outset, the less likely it will be that major factors are overlooked.

Finally, in addition to getting the right participation and adequately describing the risk situation, one of the most important factors in risk characterization is to ensure that adequate scientific and technical information is available to support the decision. To help focus this effort, various diagnostic questions should be asked about the hazards and the risks, including (Stern and Fineberg, 1996):

- Who is exposed?
- Which groups are exposed?
- What is posing the risk?
- What is the nature of the harm?
- What qualities of the hazard might affect judgments about the risk?
- Where is the hazard experience?
- Where and how do hazards overlap?
- How adequate are the databases on the risks?
- How much scientific consensus exists about how to analyze the risks?
- How much scientific consensus is there likely to be about risk estimates?
- How much consensus is there among the affected parties about the nature of the risk?
- Are there omissions from the analysis that are important for decisions?

Risk Characteristics Important to Building Performance

Based on the concepts outlined above, a risk characterization effort was undertaken in the United States with the aim of incorporating risk into the development of performance-based building and fire regulations (Meacham 1999; 2000; 2000a). A key objective of the effort was to explore how risk could serve as a metric for defining acceptable building performance. As a first step, the building codes were reviewed and input was solicited from stakeholders relative to those occupant, building, and community risk factors that should be considered. The above list of diagnostic questions served as the basis. As a result of this effort, the following hazard, occupant, building, and community risk factors were identified.[i]

The key hazard factors identified were:

- The nature of the hazard,
- Whether the hazard is likely to originate internal or external to the structure, and
- How the hazard may impact the occupants, the structure, and/or the contents.

The key risk factors identified were:

- The number of persons normally occupying, visiting, employed in, or otherwise using the building, structure, or portion of the building or structure.
- The length of time the building is normally occupied by people.
- Whether people normally sleep in the building.
- Whether the building occupants and other users are expected to be familiar with the building layout and means of egress.
- Whether a significant percentage of the building occupants are, or are expected to be, members of vulnerable population groups.
- Whether the building occupants and other users have familial or dependent relationships.

In addition to these risk factors, which are specific to a building or its occupants, the issue of importance of a building to a community must also be considered. The key reasons that have been identified regarding why a community may deem a building or class of building to be important to community welfare include:

- The service it provides (e.g., a safety function, such as a police or fire station, or a hospital),
- The service it provides in an emergency (e.g., an emergency shelter, hospital, communications facility, or power generating station),
- Its social importance (e.g., a historic structure, a church or meeting place), or
- The hazard it poses to the community, not just its occupants (e.g., chemical manufacturing facilities or nuclear power generating facilities).

In order to integrate the above factors into a performance-based building regulation, a link is required between the hazard, risk and importance factors and the expected/desired building performance. To make this link, five key performance indicators were identified:

- Structural damage,
- Damage to systems and building operations,
- Injury and death,
- Damage to contents, and
- Damage to the environment.

Given the above risk factors, importance factors and performance indicators, and considering the natural and technological events reasonably expected to impact buildings, the raw materials are available for describing the basis of a performance-based building code. However, to operationalize the concepts into a useable code document, the relationship between the risk factors, importance factors, and performance indicators needs to be better defined.

PERFORMANCE LEVELS AND PERFORMANCE GROUPS

In addition to yielding significant information needed to better understand the risk perceptions and expectations of various stakeholder groups, the risk characterization process highlighted differences

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[i] Recall that risk is defined as the possibility of an unwanted outcome in an uncertain situation, where the possibility of the unwanted outcome includes loss of or harm to something that is valued and the event or hazard that may occasion the loss or harm.

in building performance expectations as well. In many ways, the fact that different building performance expectations exist is not surprising. If one type of building, or the occupants or contents of one type of building, is valued more than a different type of building, it follows that the buildings would be expected to perform at different levels (better performance for the more highly valued building). In some cases, a focus on this issue highlighted apparent discontinuities, such as the code allowing for lower performance when the contents or occupants were valued higher (e.g., lower performance requirements for child daycare centers than for high schools). For the most part, however, higher valued buildings led to expectations for higher performance, with benefit-cost and/or risk-cost relationships being key factors in performance decisions.

Armed with the knowledge that occupant risk, community importance, and magnitude of hazard event are central to expectations of performance, and that different performance expectations exist for different risk and importance factors, a relational performance framework was developed. In brief, the resulting framework related the central components using the concepts of *performance groups* (based on risk and importance factors), *tolerable levels of impact* (based on expected performance), and *magnitude of design hazard event*. The framework is illustrated below and described in detail elsewhere (e.g., Meacham, 2000; ICC, 2000). Critical to this discussion, however, are the concepts of design performance levels, tolerable levels of impact, and performance groups, which are detailed in subsequent sections. Key to the interaction of design performance levels, tolerable levels of impact, and performance groups is the fact that different levels of expected building performance exist.

		TOLERABLE LEVELS OF IMPACT			
		PG I	PG II	PG III	PG IV
MAGNITUDE OF DESIGN HAZARD EVENT	VERY LARGE	SEVERE	SEVERE	HIGH	MOD
	LARGE	SEVERE	HIGH	MOD	MILD
	MEDIUM	HIGH	MOD	MILD	MILD
	SMALL	MOD	MILD	MILD	MILD

Figure 1. Performance Matrix (adapted from Meacham, 2000; ICC, 2000)

Tolerable Levels of Impact / Design Performance Levels

As can be seen in Figure 1, for each magnitude of design hazard event, a level of the tolerable impact is provided for each performance group. For example, for a Large magnitude of design hazard event, the tolerable levels of impact are Severe, High, Moderate, and Mild for performance groups (PGs) I, II, III, and IV respectively. This means a building in PG IV should have only mild damage when subjected to the large design hazard event, whereas a building in PG I can have severe damage. Thus, buildings in PG I and PG IV have very different performance expectations. The four *levels of tolerable impact* are based on the risk and importance factors previously identified, including likely damage to the structure, its systems or contents; likely injuries or deaths to building occupants; and likely environmental impact. For design purposes, the tolerable levels of impact can be considered the inverse of *design performance levels* to which the structure must conform when subjected to design loads of various magnitudes (expected performance).

The tolerable levels of impact were developed based on an understanding of current building performance, hazard event and loss experience, and public perceptions and expectations of the level of safety and risk provided by buildings in the event of natural and technological hazards. Although there is a continuum of tolerable impacts ranging from 'clearly tolerable' to 'clearly intolerable,' it is more difficult to characterize the impacts along a continuum than it is to characterize the impacts as a set of finite and well-defined limits or thresholds. Thus, the levels of tolerable impact are characterized by classes (groupings) for ease of analysis and design. As with the magnitudes of design hazard events, these levels should adequately reflect risk or damage thresholds that interested and affected parties readily agree to.

Although four levels of tolerable impact (or conversely, design performance levels) are used here: Mild, Moderate, High and Severe, other divisions may be equally suitable (e.g., three or five). The key is that establishing these levels of impact requires a balance of technical knowledge and ability with societal values, perceptions and expectations. The levels of tolerable impact as used here are defined as follows:

Mild Impact

- There is no structural damage and the structure is safe to occupy. However, cosmetic damage may occur and some clean-up will likely be required, thus requiring some delay in reoccupying some areas.
- Non-structural systems needed for normal building use and emergency operations are fully operational. This includes such systems as electrical power, ventilation and plumbing systems.
- Injuries to building occupants are minimal in numbers and minor in nature, with a very low likelihood of single or multiple life loss.[ii, iii]
- Damage to building contents is minimal in extent and minor in cost.[ii, iii]
- No hazardous materials are released to the environment.

Moderate Impact

- There is moderate structural damage that is repairable; some delay in re-occupancy can be expected due to structural rehabilitation.
- Non-structural systems needed for normal building use are fully operational, although some cleanup and repair may be needed. Emergency systems remain fully operational.
- Injuries to building occupants may be locally significant, but generally moderate in numbers and in nature. There is a low likelihood of single life loss and a very low likelihood of multiple life loss.[ii, iii]
- Damage to building contents may be locally significant, but is generally moderate in extent and cost. [ii, iii]
- Some hazardous materials may be released to the environment, but the risk to the community is minimal. No emergency relocation is necessary.

High Impact

- There is significant damage to structural elements but no large falling debris; repair is possible. Significant delays in re-occupancy can be expected.

[ii] Applies only to hazard-related applied loads.

[iii] The nature of the applied load (i.e., fire hazard) may result in high levels of expected injuries and damage in localized areas, whereas the balance of the areas may sustain less injuries and damage.

- Non-structural systems needed for normal building use are significantly damaged and inoperable; egress routes may be impaired by light debris; emergency systems may be significantly damaged, but remain operational.
- Injuries to building occupants may be locally significant but are generally moderate in numbers and nature. There is a moderate likelihood of single life loss and a low likelihood of multiple life loss.[ii, iii]
- Damage to building contents may be locally total and generally significant.[ii, iii]
- Hazardous materials may be released to the environment with localized relocation needed for buildings/structures in the immediate vicinity.

Severe Impact

- There is substantial structural damage, but all significant components continue to carry gravity load demands. Repair may not be technically possible. The building is not safe for re-occupancy, as re-occupancy could cause collapse.
- Non-structural systems for normal building use may be completely non-functional. Egress routes may be impaired; emergency systems may be substantially damaged and non-functional.
- Injuries to building occupants may be high in numbers and significant in nature. Significant risk to life may exist. There is a high likelihood of single life loss and a moderate likelihood of multiple life loss.[ii, iii]
- Damage to building contents may be total.[ii, iii]
- Significant hazardous materials may be released to the environment, with relocation needed for several blocks or more.

Note the use of the terms “may” and “likelihood.” These qualifiers reflect the fact that the above levels of tolerable impact are *design* levels, and that there is some probability that an actual event will exceed the design impact thresholds.

Performance Groups

To assess whether buildings would meet the performance expectations, magnitude of design hazard events and levels of tolerable impact have been suggested. Although one could consider each individual building, or each building use or occupancy classification independently, it was felt that a more efficient approach was to consolidate building uses into *performance groups,* where the same levels of tolerable impact exist for the same magnitudes of design hazard event. In other words, if buildings which are classified under five different uses or occupancies are expected to perform in the same manner when subjected to a common set of design loads, those five building uses could form a common performance group.

Although the concept seems simple, there are considerable challenges in consolidating numerous building uses into smaller performance groups. Principal amongst the many challenges is the selection of the criteria against which to judge whether a building use fits in one performance group or another. Here again, the occupant risk, property protection and community welfare (importance) criteria can be used for this purpose.

To fit with the overall framework, performance groups must be established by identifying the maximum level of tolerable impacts (design performance levels) that are desired for buildings or building uses when subjected to the largest magnitude of design events. As with the magnitudes of design loads and levels of tolerable impact described previously, four performance groups are used here: Performance Group I, II, III and IV.

Performance Group I (PG I) is the minimum level of performance with which all structures posing a very low risk to human life, should the structure fail, need to comply.

Performance Group II (PG II) is the minimum level of performance with which all structures subject to the ICC Performance Building Code, except those classified as Performance Group I, Performance Group III, or Performance Group IV must comply.

Performance Group III (PG III) is the minimum level of performance with which structures of an increased level of societal benefit or importance must comply. (These structures and classes of structures have increased levels of performance as they house large numbers of people, vulnerable populations, or occupants with other risk factors, or fulfill some role of increased importance to the local community or to society in general.)

Performance Group IV (PG IV) is the minimum level of performance with which structures that present an unusually high risk or which are deemed essential facilities must comply. (These structures and classes of structures have increased levels of performance as they are expected to continue in operation after a hazard event with little or no damage.)

SUMMARY

It has been posited that performance-based building regulations need to address multiple levels of building performance, as there are differing performance expectations for buildings (structures) depending upon such factors as the use of the building, the characteristics of the building occupants, and the importance of the building to the community. It has been further suggested that 'risk' may serve as a suitable metric for assessing performance and establishing different performance levels that different buildings and building types should attain. As a means to better understand and regulate for various expectations of building performance, a framework has been developed which incorporates and relates the concepts of *performance groups*, *tolerable levels of impact*, and *magnitude of design hazard event*. This framework will enable policy makers to communicate to designers what is expected from buildings with regard to performance. Although not discusses herein, the concepts described in this paper have been incorporated into the final draft of the *ICC Performance Code for Buildings and Facilities* (ICC, 2000), which if accepted by the membership of the model code organizations in the United States, will become the first all encompassing performance building code for the United States.

CONCLUSION

Not all buildings perform the same, nor are they all expected to. For a performance-based building regulatory system to be as effective as possible, this realization has to be recognized and addressed within the system. For performance under hazard-induced design loads, it has been shown that risk and importance to the community can serve as metric for describing tolerable levels of performance for a wide range of building uses. Although not discussed in this paper, this approach is applicable to the evaluation and assessment of existing buildings, and for modification to existing buildings, as well as to new construction. Likewise, although not discussed herein, the concepts of different performance expectations and multiple levels of performance can be, and likely should be, extended to other aspects of building performance, such as useability, functionality, and amenity. For these areas, metrics other than risk and importance will likely be required, but the conceptual approach is applicable. As performance-based building regulatory systems evolve, the inclusion of performance expectations and multiple levels of performance will and should play a larger role in helping to gain acceptability and uniformity of performance-based designed buildings.

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