PERFORMANCE-BASED BUILDING CODES: WHAT WILL HAPPEN TO THE LEVELS OF SAFETY?

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Introduction

Performance-based building codes have been under development in various countries for the last two decades. The United States has been one of the last major countries to start such an effort, but such development is well underway here, with the notable landmark being the issuance of the first draft of the IBC (International Building Code) performance-track code in 1998 [1]. Simply put, performance-based design, when applied to fire safety, means the use of fire safety engineering for design purposes. Here, I will draw a carefully narrow definition of "engineering": problem solving by a quantitative application of scientific laws. By this definition, fire safety engineering is a profession hardly 30 years old. This is because fire safety science, which is the pertinent science, has only been in existence for about that time period. Fire protection technology, by contrast, means the application of established principles toward fire protection. Fire protection technology, of course, is more than a hundred years old. Its origins in the US date to the various means that New England mill owners in the first half of the 19th century were already using to minimize fire losses in mills.

Structural design, by contrast, has been done on the basis of engineering, rather than empirical technology, for close to 200 years now. In much of the discussion in building codes, there is an automatic leap made that, if structural design can be reliably done on an engineering basis, all that is needed in the fire safety area is to emulate the strategies used there, and fire safety aspects of building codes can readily be converted to a performance (i.e., engineering) basis.

If fire safety design of buildings is done on an engineering, instead of the conventional prescriptive basis, there can be several significant advantages:

- resources can be allocated to meeting real needs, instead of satisfying code provisions which may be ineffectual or unnecessarily duplicative;
- a rational design may be made in projects which are sufficiently unconventional to not be amenable to analysis under prescriptive codes; and
- an owner desiring to increase the level of safety over the legal minimum has a rational tool for doing do.

But there are significant pitfalls to a hasty adoption of performance-based fire safety design, and in this paper I will examine some of the most salient one.

The IBC proposed scheme

The IBC proposal is a surprisingly-slim document which is modeled after a scheme adopted in New Zealand in the early 1990s. The New Zealand scheme comprised a 5-level 'pyramid,' with the levels, top-down, being: Objectives; Functional Requirements; Performance Criteria; Verification Methods; and Examples of Acceptable Solutions. The IBC scheme adopted only the top two levels—Objectives and Functional Statements. The document is nearly totally non-quantitative and is generally couched in a language of 'sufficiency.' Here are some examples, a bit condensed, that illustrate the approach:

- The available escape time shall be greater than the time for untenable conditions to develop.
- Appliances and services shall be installed so that they will not become a source of ignition.

- Wall, floor, and ceiling assemblies shall limit the spread of fire.

The lower levels of the pyramid have been devolved upon SFPE, who have presented a draft Engineering Guide [2]. In its current state, the SFPE document is basically only a set of annotated flow charts explaining how the design work should be organized. It does not set down any quantitative rules or limits.

The IBC approach is perhaps unique so far, in that compared to other countries, there is generally no numerical guidance contained within it. An examination of other countries' strategies [3], however, has shown that while most of them do contain equations and other numeric guidance, the guidance is generally voluntary rather than obligatory. Thus, the US scheme, while somewhat extreme, has precedents elsewhere. The precedents are not necessarily salutary, and I will now look at what some of the expected problems can be.

Pitfalls and problem areas in performance-based design

The general concern is that, if implemented the way now proposed, the IBC Performance Track will lead to designs where much less fire safety is being provided than under current, prescriptive regulations. This can be of major concern, since the performance track will generally be used for large, high-dollar projects. These are projects where the highest number of persons is at risk. Thus, a certain irony will be created, since smaller, mundane projects will still be designed under the prescriptive track. Thus, facilities where large numbers of people congregate will have lower safety standards than those where only a small number are gathered.

The major problem areas include the following:

- the level of safety is not quantified (e.g., risk computations are not made)
- quantitative performance evaluation formulas are not offered to determine if any particular fire safety subsystem is adequate
- redundancy is considered as something to expunge, not as a valuable aid to safety
- an assumption is built in that fire dynamics are fully known
- designs start with, and are largely based on, fire scenarios which the designer is free to define or select
- the role of tests in determining the fire performance of products is reduced or absent.

Levels of safety

If a commitment is not made to maintain the level of safety in the new system to be similar to the old one, the only probable result can be a drastic dropping of safety levels. Fire safety is generally provided for an individual by someone else (the employer, the hotel owner, the speculative builder, etc.), not by himself. Since it is not an amenity, it is largely invisible to the layman, and it costs money, the situation is clearly stacked in favor of reducing fire safety. The main plausible counter-force is an effective building code. However, it is impossible to conceive of fire safety levels not dropping if a policy of maintaining them is not even *enunciated*, much less successfully implemented.

It is by no means an easy feat to quantify the level of safety. Industrial engineers would point to the fact that levels of safety are routinely quantified by means of probabilistic risk assessment (PRA). However common this outlook may be in other fields, the prudent observation is that such PRAs are rarely evaluated as to their realism or lack of bias. The Rasmussen report is perhaps the most notorious example of how inadequate [4] this approach can turn out to be in practice.

The IBC performance track does not even consider how to quantify the level of safety, with "sufficiency" being viewed as an adequate principle. Perhaps the simplest way we can reflect on this is to point out: What is "sufficient" to the landlord may be "irresponsibly negligent" to the tenant. Taking for example escape time, usually the designer will posit some design fire. He will then use some well-known, but dubiously validated, escape model to demonstrate that even though he has omitted various safety features which would be mandated under prescriptive requirements, everyone is able to exit before untenable fire conditions descend. All safety features will be assumed to be 100% operative. Nobody will be disoriented, nor back-track, nor proceed down a staircase where he cannot exit due to ongoing construction works, etc.

Arguments can be made in general for either tightening or loosening fire safety minimums. If resources are seen as being in short supply and an imbalance of priorities is seen, society should make corrections. But these corrections should be made overtly, by people's elected representatives, not inadvertently or surreptitiously by building designers. Judging by present indicators, FSE-based designs are precisely likely to lower fire safety levels without the public's awareness or input.

Quantitative evaluation of performance

It should not need to be argued that any viable performance-based building regulation **must** contain within it quantitative measures for evaluating whether a design is adequate. It may be necessary for the benefit of individuals not intimate with the engineering design process to explain the difference between a design method and an analysis (or evaluation) method. For most engineering problems, there may be more than one, unique design which fulfils all of the specified requirements. To illustrate with a very simple structural example, a structural column can be a hollow steel tube, a reinforced-concrete member, a laminated timber post, etc. The strategies for designing each one are going to be quite different. Yet a numeric rule for an *evaluation* can be formulated which is general. For instance, such a rule may say that "the member must show a safety factor of x against compression or buckling failure." This rule is then supplemented by additional rules which provide the minimum loadings and the maximum strengths of materials which are allowed to be assumed.

What is curious is that, of all the countries which have drafted performance-based building codes so far, only one country—Japan—has seen fit to even state as an explicit objective that as many fire-safety subsystems as possible will be provided with a quantitative performance assessment formula. It could be done either by ICC directly or developed on SFPE, but it is my opinion that a robust performance-based code cannot be achieved without creating such quantitative performance criteria. An example of this process which is perhaps more readily available to the Western world are the Eurocodes which have been developed in Europe. These are elaborate documents governing the structural design of various types of constructions. The Eurocodes contain sections on structural fire design, and these sections all provide mandatory quantitative criteria.

The role of redundancy

Traditional, prescriptive building codes have achieved a sizeable fraction of their safety level by redundancy. Commonly, they mandate fire endurance AND restrict fuel load in various ways AND require fire sprinklers AND a whole host of other arrangements. It can certainly be argued that any one of these measures should obviate the need for the others. Unfortunately, not only has this been argued, but authorities have often been persuaded by such an argument. Perhaps it is best here to point out that **there have been very few major fire disasters which did not involve a series of failures**. Under traditional fire protection philosophies, if any one safety system fails, normally what results is a nuisance fire, not a disaster. Catastrophes tend to take place only when a string of failures occur in a row. But redundancies cost money. And with the "sufficiency" viewpoint of the FSE-based design schemes, it is all too easy to purportedly demonstrate that everything suffices.

One might consider the fact that reliability analyses done in other technical fields often contain a mechanism for explicitly allowing for out-of-commission devices and systems. But, at the present time, this would seem to be extremely difficult to implement in the fire safety area. There are two reasons for this:

1. only the most crude of failure statistics are available in the fire safety area
2. most of the failures are due to human negligence, not mechanical fault.

Fire doors fail occasionally because they wear out; much more commonly they fail because somebody chained the door shut or propped it open. Prof. Brannigan has provided a thoughtful exposition on the difficulties of quantifying failures which are due to human actions [5].

The role of fire dynamics

One feature which is very striking in most of the FSE-based design schemes is the assumption that fire dynamics is perfectly well known. As outlined above, fire safety engineering is a young profession. Most observers would consider that it is at a stage where, say, civil or mechanical engineering was about 50 years ago. While certainly there must have been some civil or mechanical engineers 50 years ago who felt that all of the underlying science needed for their profession was already known, clearly such would have been limited thinking. Yet most of the performance-based codes around the world, including the one by ICC, seems to have been developed under that same impression.
There are two areas of concern here:

1. The world's *experimental data base* in fire physics and chemistry is immature and limited, especially so as concerns large buildings or spaces. Very few experiments have been reported in spaces more than 3~4 m in scale, yet FSE-based designs are precisely being advocated for some of the world's largest engineering projects.
2. The development of *engineer tools*, i.e., computer codes which are used to apply the fire dynamics knowledge to design problems, is stagnant and is receiving minuscule governmental-agency support.

The lack of recent progress in experimental fire dynamics can perhaps most easily be seen by comparing the second edition of the SFPE Handbook to the first one. The first edition, published in 1988, was a phenomenal leap forward over what was available before. But the second edition in 1995, while incorporating more material in certain areas remote from fire physics/chemistry, shows only small advances over the first in the crucial fire dynamics area. This is because the needed new research to include simply was not there. Based on available fire dynamics data, designers often have to make extrapolations of 1 or 2 orders of magnitude. Yet at the moment, there seems to be little hope that needed research will be undertaken to fix this situation. Much of it has to do with government funding and priorities, but it is also a major limitation that there are so few universities have established fire safety engineering departments. While useful research results can and do emanate from chemistry, mechanical engineering, and other allied departments, nonetheless one can hardly expect such faculties to focus strongly on the needs of the FSE profession.

Nearly all of the FSE-based design approaches make the assumption that a major engineer tool will be a computer fire model to calculate the presumed effects of fire. The quality of a scientific computer program, in turn, can be divided into two main aspects: (1) the quality of the physics embedded in it; and (2) the mathematical competence with which the solutions are undertaken. I will not address point #2 here, but point #1 clearly requires that competent physics be built in. Examining the shortcomings of the fire models of 1994, I concluded that there were a number of very basic deficiencies [6][7]:

- No flame spread predictions
- No heat release rate predictions
- No fire chemistry, especially CO
- No smoke chemistry
- Absence of realistic layer mixing
- No suppression.

These deficiencies primarily reflect areas of fire dynamics which are inadequately known, although in some cases phenomena known on a research level have failed to show up in engineer tools. What is of concern is that in the intervening five years, not only has a new generation of engineer tools not been seen, but the areas of fire dynamics needing research failed to attract it.

The basic inaction appears to stem from the hermetic nature of a common designer's view of design fires. Thus, I must address this issue next.

Design fires

A cornerstone of all FSE-based approaches is starting with a design fire. This is reasonable, but how should that design fire be determined, though? Because of our inability to establish a plausible quantification of risk, currently in most FSE-based codes the decision is left up to the designer. There may be some implied onus that he should select a "relatively severe" fire scenario, but how is that to be agreed upon? Airplanes do, on rare occasions, crash into buildings. Should buildings be designed to resist airplane crashes? Most of us would say No, but a further consensus seems hard to see.

A few years ago, Margaret Law wrote a very interesting paper where she castigated UK designers for mindlessly selecting a 5 MW design fire in inappropriate situations [8]. It turns out that there has been one category of situations—sprinkler-protected shops opening onto an enclosed shopping mall—for which a 5 MW fire has been rationally determined to be a conservative value. But then numerous designers, adopting the principle that "In a storm, any port will do," proceeded to use this design fire for situations where no rationale whatsoever had been developed. If rational bases for a certain design philosophy are not available, it would only seem prudent to avoid using that type of design, in preference to committing design improprieties.

Law focused on a steady-state peak heat release rate (HRR) value, but the growth period is also of much concern in considering fires which may occur. Here, and equally troublesome situation exists [7]. Typically, designers using FSE-based codes do not attempt to delineate an actual HRR curve. Instead, it has become a tenet of the profession that all real fires can be closely matched up to one of four idealized fires, termed 'slow,' 'medium,' 'fast,' and 'ultrafast.' This approach has now been used for so much engineering work that many practitioners feel that it is soundly based in fire physics—yet this is far from being true.

The use of the t^2 fires first arose in the early 1970s, when quantitative performance evaluation of fire detectors was first being attempted. It was noted that the HRR from fires could have different rates of rise and this would affect the response of the detector. Thus, a series of fire-growth-rate categories was set up to aid in such detector studies. This was subsequently popularized when it became part of the standard NFPA 72 [9]. It is important to note carefully the original application—characterizing the response of fire detectors. A fire detector should alarm very early in the fire, before it is a threat to any occupants. This level will typically be less than 100 kW. For such small fires, declaring that there are only four distinct fire types is a reasonable decision. In fact, the designer of a detector would not know what to do with any greater amount of detail about the fire. But, once the detector designer has provided adequate responsivity for such a small fire, his job is finished; larger fires are not a concern to him. Indeed, a much larger fire will destroy the detector itself.

Such small fires, however, are not the appropriate focus for modeling the general fire hazard in buildings. Even in structures of very low combustibility, occupant goods can provide fires yielding megawatts, not kilowatts. Yet, the detector designer's four schematic fire types have simply been extrapolated by several orders of magnitude; for instance, a review paper [10] shows these t^2 fires extending up to 30 *mega*watts.

In the world's fire literature, there are very few objects over about 3-5 MW whose HRR curves have ever even been described.

Equally problematic is the notion that the designer (or a code-writing authority) should match up potential burning objects against some chart which tells him which t^2 curve to select. While several studies have been published showing how (with some poetic license) a t^2 curve may be fitted to measured HRR data *a posteriori*, no such work has resulted in a general scheme whereby combustibles might be classified correctly before testing.

The role of fire tests in performance-based designs

It has been axiomatic in fire safety engineering that testing products is an essential means by which safety is promoted. One might ask Why? Two rather different reasons can be seen:

(1) Fire tests provide numbers which can be incorporated into a quantitative design, or be used to demonstrate a passing result with regards to some particular regulation.
(2) Fire testing promotes the improvement of fire safety characteristics of products.

The first reason is self-evident. The second reason has not been much explicitly discussed, but it is actually a very significant benefit of fire testing. If a manufacturer is required to test products for flame spread, ignitability, HRR, etc., and finds that his results are among the worst possible, a strong incentive occurs for him to reformulate or improve his product. Good results can be used in advertising, for example, even if the products could be sold to certain markets without improvement. Thus, simply the presence of testing requirements has an effect in raising the average performance of products in the marketplace.

If design methodologies are emplaced, however, which prejudge product performance without testing, then the need for fire testing can only be expected to diminish. While the benefits of reason #2 are hard to quantify, it should be very clear that they are real, nonetheless. Such benefits stand to be lost if design strategies which prejudge products become dominant.

It is also unclear how honestly designs can proceed if products are not tested. Wall linings, occupant goods, and a wide variety of other commodities exist which can show extremely poor fire behaviour. If design schemes are advanced which need to 'tolerate' such commodities, then exceedingly fast-growing, high intensity fires would have to be routinely designed for. More likely such a realization will end up motivating the less-scrupulous designer to artfully arrange other problem assumptions in such a way as to seemingly create a benign situation. This inducement to cutting corners cannot be viewed as healthy.

Recommendations

The above issues of concern are all solvable, so some strategies for success can at least be outlined.

- Efforts must be made to quantify the level of safety.
- The appropriate level of safety must be selected explicitly by elected officials, not by building designers.
- Design methods must be fostered which are based on fire test results, in preference to ones which prejudge products.
- The necessary role for redundant protection features must be studied and incorporated into design methods.
- Means must be found for invigorated funding of fire dynamics research and of development of computer fire models.

And finally, and perhaps most important.

- Steady progress is better than precipitous action.

The final consideration is that to develop a workable, safe performance-based building code is **a very difficult endeavor**. Many of the prerequisites needed are simply not in place today. Thus, working towards the day when FSE-based fire safety designs will flourish is a noble effort, but precipitous haste is not. The consequences of such haste are likely to be erection of buildings with serious fire safety shortcomings.

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