A VISION FOR A COMPLETE PERFORMANCE-BASED EARTHQUAKE ENGINEERING SYSTEM

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SUMMARY

Performance-based earthquake engineering is being formally developed by several countries, and various aspects of performance-based seismic design are popular research topics. However, this work is not well coordinated and there is little consistency in terminology or methodology. A procedure for development of performance-based codes previously has been developed for other disciplines and seismic codes should be consistent with this procedure. The key component needed for further development of performance-based earthquake engineering is a reliable, consensus based verification procedure. Regardless of complexity, this “performance predictor” (“performance engine” is the term used in this paper) could be used to verify the adequacy of the procedures used for all earthquake engineering tasks as well as make them consistent and interchangeable. These tasks include development of codes at various levels of complexity, design of new buildings in general, evaluation and retrofit of existing buildings, ratings of buildings for economic uses, regional loss estimating, and post earthquake data collection. Additional advantages include transportability of designs and research results between countries.

INTRODUCTION

Performance-based earthquake engineering, for the purposes of this paper, encompasses the full range of engineering functions--design, evaluation, loss estimation, code-writing, post-earthquake reconnaissance and data gathering, and research–and is based on the assumption that the performance of a given structure, for a given ground motion, can be predicted with an acceptable accuracy and known reliability. Although this paper concentrates on buildings, performance-based earthquake engineering can be applied to bridges, other lifelines, or even green-field sites. Performance-based earthquake engineering is intended to be more general than *performance-based codes*—which are only one product of performance-based earthquake engineering, or *performance-based design*—which only covers a narrow design function.

In the last ten years, particularly due to damage from the Loma Prieta, Northridge, and Kobe earthquakes, interest has grown worldwide in performance-based earthquake engineering techniques. Unfortunately, due to a lack of uniform definitions and standards, the work in various countries is not coordinated and seldom transportable, despite bilateral workshops and other cooperative efforts (e.g., [Fajfar, 1997], [Shimazu, 1999]). Despite the great interest in performance-based earthquake engineering, there is a lack of appreciation of the powerful and wide-ranging effects that a fully developed performance-based earthquake engineering system would have on the field.

The most development has occurred in the area of performance-based codes, where a history of conceptual development exists by other disciplines. However, this work has never been considered in systematic context within the rich and varied field of earthquake engineering. There is also a common misunderstanding that a performance-based code consists merely of the provision of various performance standards that can be chosen by an owner, rather than a systematic application of performance-based earthquake engineering at several different levels in code development and application.

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It is envisioned that performance-based earthquake engineering, using a common and interchangeable platform of performance descriptions and prediction, can be applied:

- to refine simplified code design;
- to provide a valid option to code design at various performance levels;
- to improve evaluation and retrofit of existing buildings;
- to improve and refine regional loss estimation;
- to improve the applicability of post earthquake reconnaissance, and
- to improve the efficiency of earthquake engineering research.

PERFORMANCE-BASED BUILDING CODES

A common misconception is that performance-based earthquake engineering begins and ends with a performance-based building code. This focus has created a high level of interest and a large body of development work in this area. However, the proper integration of performance-based provisions into seismic codes is also commonly misunderstood as simply replacing the traditional prescriptive single-performance-level code with a code that offers multiple performance levels. Instead, code development within performance-based earthquake engineering should follow the procedures developed over many decades for more generic performance-based codes.

Conceptual development of performance-based codes began early in the twentieth century and has resulted in several generic performance-based codes including those in England, New Zealand, and Australia. These generic performance-based codes create a process that can be applied to any aspect of building design. To date, much of the use of these performance-based "shells" has been in the area of fire safety. Currently, a renewed interest in performance-based codes, including performance-based seismic codes, may extend this use to many other areas of building design. The process that has been developed includes methods for defining *Performance Objectives*, *Performance Requirements*, and *Acceptability Criteria.* The performance-based code design methodology normally will not replace the traditional prescriptive methods, but will be in parallel with them as an acceptable alternative. Most buildings will continue to be designed using the simpler, prescriptive approaches.

A good comparison of prescriptive and performance-based code provisions in the area of fire protection has been made by Milosh Puchovsky of the National Fire Protection Agency in the U.S., and is shown in Table 1.

Table 1: Comparison of Prescriptive and Performance Codes [Puchovsky, 1996]

Prescriptive Based	Performance-Based
Addresses generic occupancy groups	Can be applied to any group
Provides for fire safety through a combination of prescriptions	Achieves specific fire safety goals for a specific application
Based largely on judgement, experience, and empirical methods	Relies heavily on scientific and engineering principles
Easier to enforce, particularly by administrators not having the level of experience or education of the designers	More difficult to enforce and administer by code officials
Rooted in the 19^{th}-century	A 20^{th} –century development
Does not result in a "quantifiable" degree of fire safety	Develops a "quantifiable" level of fire protection

In the U.S., the new model building code developed to replace the three currently in use, scheduled to be published in the year 2000, will include a performance-based component [ICC, 1998]. This code, *2000 International Building Code,* has been developed by the International Code Council (ICC). According to the

ICC, their effort with performance-based codes is not intended to eliminate the current prescriptive provisions, but instead as a restructuring of the code system. This restructuring will include the prescriptive code as a design option, but will no longer consider a design utilizing the "alternate materials and methods" section as a variance from the code.

Previous work in generic performance-based codes includes a description of the steps necessary for a fully functional code in a specific design area. These steps are shown in Figure 1. The key characteristics to be noted are the flow from top to bottom and the need to develop overall verification criteria first, before prescriptive-type code provisions are developed--so that the prescriptive provisions can be validated by the verification criteria. Further, the true performance-based verification criteria become available to form a clear and acceptable alternate to strict prescriptive code design procedures. A slightly different version of the same process is shown in the ICC draft performance-based code (Figure 2).

Related specifically to earthquake engineering, the process shown in Figures 1 and 2 can be made more specific, as shown in Figure 3. Note that a credible verification procedure will enable development of codes to suit a desirable performance level, and, more importantly, for the first time, will enable policy makers in each region or country to set appropriate goals for normal, special, and emergency buildings in their local code. Traditional, relatively prescriptive requirements can be developed for code use, and checked for appropriate performance using the verification procedure. For specific building types, completely prescriptive and relatively foolproof simplified provisions can be developed with confidence that they are equivalent to the primary code. Examples of such simplified and highly prescriptive codes that are not now checked for equivalency include the Conventional Construction provisions for small wood buildings in the U.S. and the stand-alone codes for certain simple building types used in China [Ministry, 1994]. As shown in Figure 3, the general verification procedure can be used directly for design purposes for special or unusual buildings that have unique seismic requirements.

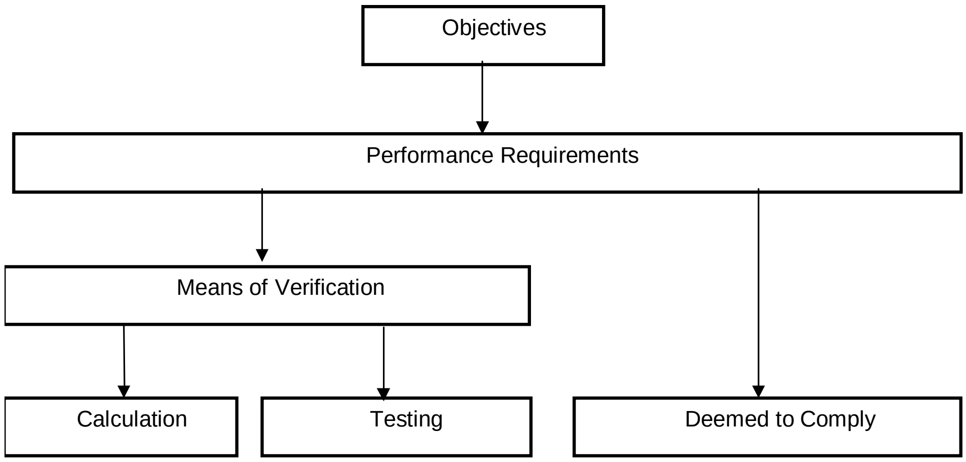

Figure 1: The Basic Performance Base Code Process

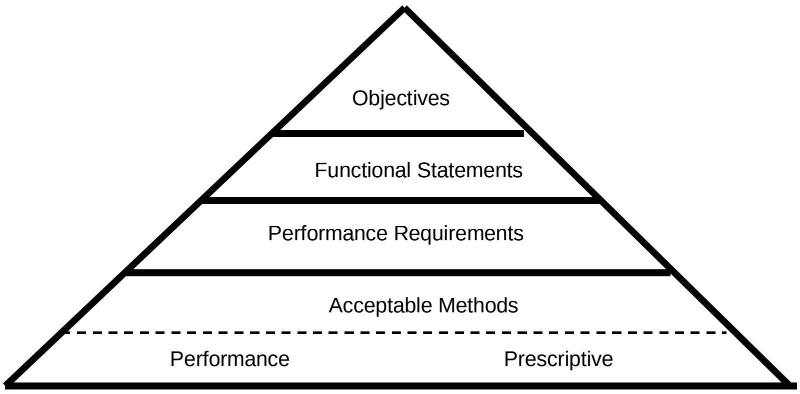

Figure 2: The ICC Performance-Based Code Process (adapted from [ICC, 1998])

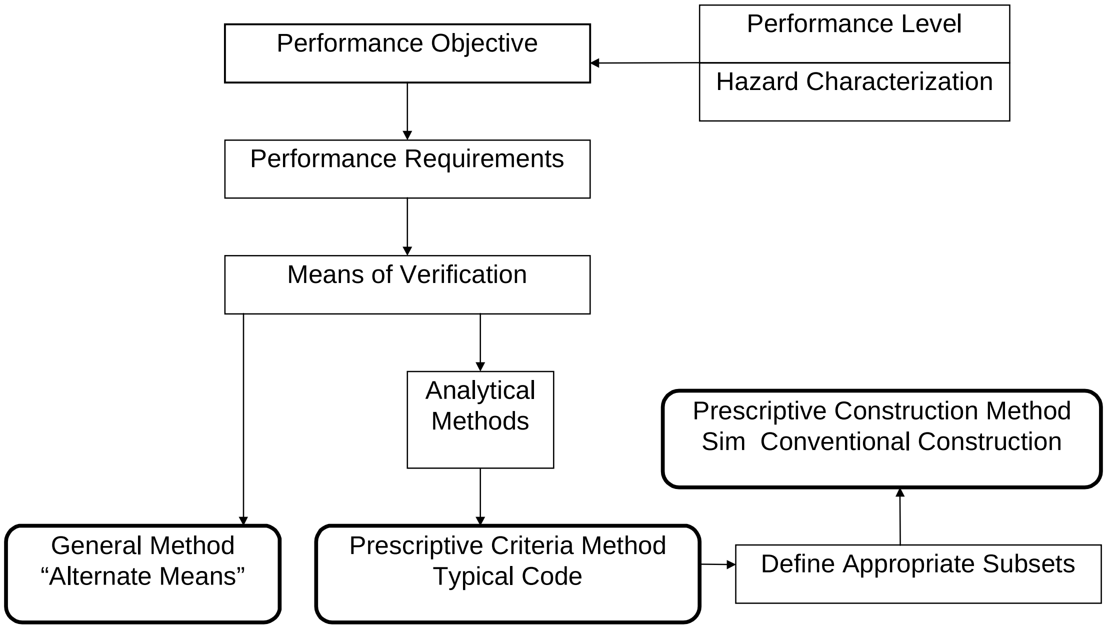

Figure 3: The Performance-Based Code Process Applied to Seismic Design [Hamburger, 1998]

Clearly, the missing link currently for development of performance-based codes is the lack of a reliable and acceptable "means of verification". For performance-based earthquake design purposes, this key element would consist of an analytical procedure, supplemented by testing as necessary, that could reliably predict performance of a structure for various ground motions. In this paper, the verification procedure will be termed a "performance engine."

OTHER APPLICATIONS OF A "PERFORMANCE ENGINE" IN EARTHQUAKE ENGINEERING

The verification procedure or performance engine needed for codes would have additional far-reaching applications in earthquake engineering. In fact, such a performance engine could bring together and put on a common platform all aspects of earthquake engineering. As described above, traditional semi-prescriptive code design, highly prescriptive simplified code design, and special one-off designs could all have consistent performance expectations with known reliability. Other applications, perhaps not commonly considered, are discussed below.

Evaluation and Retrofit

It is difficult to use codes and other design standards for new buildings for the purpose of evaluating older non-compliant buildings. As a consequence, many regions and countries have developed special documents for this purpose. Often these special standards use methods completely removed from new building design and consistency of seismic performance goals is therefore questionable. A prime example is the new U.S. document, FEMA 273, *NEHRP Guidelines for Seismic Rehabilitation of Buildings* [FEMA, 1997]. This document is a major advancement in seismic design for the U.S., on a par with ATC 3-06 [ATC, 1978]. It employs many new features including a performance basis, displacement based design, and simplified nonlinear analysis procedures. However, the lack of an independent performance engine to verify performance levels, or to calibrate with the traditional codes for new buildings, has hurt the credibility of the document. In fact, the U.S. currently has three documents, FEMA 273 for rehabilitation, FEMA 310 [FEMA, 1999] for evaluation, and the codes for new buildings, that often give inconsistent results for similar performance goals.

Seismic Ratings for Economic Use

Many banks and insurance companies worldwide use Probable Maximum Loss (PML) as a measure of seismic risk to buildings. PML is a statistically based parameter, measuring direct damage as a ratio of repair costs to replacement cost. Although first defined by Steinbrugge (Steinbrugge, 1982), many PML calculations rely on ATC 13 [ATC, 1984], a compilation of expected damage to buildings in California based on expert opinion.

Some computerized calculation methodologies for certain building types have been updated with actual earthquake damage statistics, but little useful data exists. There is no common method of determining a PML based on engineering evaluation, or considering compliance with various codes and standards. As a result, PML values from different consultants can vary considerably and the values have little credibility among earthquake engineers. A performance engine could be used to create a more accurate and consistent methodology for measuring economic risk to a building, as well a tying the rating to codes and evaluation methods.

Regional Loss Estimating

Regional loss estimates are used to raise local awareness, for post earthquake emergency planning and response, and to study regional mitigation measures. Building damage functions are often statistically based, and have the same shortcomings as Probable Maximum Loss calculations. Recently, an analytical loss methodology was developed for HAZUS, the FEMA funded national loss estimating method developed for the U.S. [Kircher, 1997]. This methodology has the added advantage that it is based on pushover analysis that also has been used for evaluation and retrofit of existing buildings. This crossover between different earthquake engineering tasks gives a glimpse of the tremendous advantages that could be realized from a credible and consensus performance engine. Using a common basis, modelling of inventory for regional loss estimates could directly take advantage of knowledge of buildings or groups of buildings with known code compliance or available engineering analyses. Commonly calculated losses, such as direct repair costs, building downtime, and casualties, could be directly tied into mitigation measures, which presumably would also be evaluated using the same performance engine.

Collection of Post Earthquake Damage Data

There is no consensus method for collecting earthquake damage data. There is no common vocabulary to describe earthquake damage. Each earthquake in each country is investigated to a degree consistent with available funding and the political climate. Seldom has useful statistical data been collected. Even for similar building types, data is rarely transferred between countries. A consensus performance engine could create a standard to describe damage and collect statistical information that could be used to determine its reliability, as well as increase the accuracy of other statistically based earthquake engineering tasks.

Advantages

Many of the advantages of the availability of an acceptable performance engine within a given country are obvious. If such an engine could be accepted on a worldwide scale, bringing earthquake engineering to a common basis, the advantages would multiply. Initially, it would facilitate the primary reason for interest in generic performance-based codes—international transportability of designs. Although regions may adopt different code performance levels for socio-economic reasons, any design based on the accepted performance engine could be targeted for the appropriate or required performance—anywhere. Additional benefits include automatic transportability of earthquake damage data and a common research and education basis.

THE PERFORMANCE ENGINE

There are many issues related to the complete implementation of performance-based earthquake engineering, some of them political rather than technical. Some of these include:

- providing a forum to determine appropriate performance objective for local codes;
- communication of the reliability limits of the procedure to all users;
- overcoming natural inertia to revise codes, if the performance engine indicates that this is necessary;
- converting not only codes, but all other earthquake engineering tasks as detailed in the section above to the common basis;
- administering construction if the performance-based option becomes prevalent.

But obviously, the most basic need to move development and implementation forward is a performance engine with known reliability and consensus acceptance by the earthquake community. In order to take full advantage of the potential, the performance engine should have the following characteristics:

- must predict performance for any ground motion, including those representing both statistically determined design criteria and individual events;

- duration of ground motion and structural degradation must be considered; a damage index similar to Park and Ang [Park, 1984] may be needed to yield sufficient information for loss determination;

- must be able to model ductile and brittle elements;

- outputs must include risk of casualties, damage translatable to repair costs, and damage translatable to building downtime;

- the reliability of outputs must be explicitly stated;

- to gain acceptability for all of the uses described, the procedure must have formal or informal consensus, preferably worldwide.

The development of such a performance engine could not be even considered without the ongoing rapid advances in computer speed and capacity. Nevertheless, the vision may still be incredulous to some. However, researchers in performance-based earthquake engineering, while pursuing short-term advances, should keep this long-term goal in mind.

CONCLUSIONS

Tremendous advantages are available from the availability of a consensus method to predict earthquake performance with a know reliability. Not only will this facilitate development of more finely turned codes, but it would also make consistent and tie together design of new buildings, evaluation and retrofit of existing buildings, economic ratings of buildings, regional loss estimating, post earthquake data collection, and research.

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