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Thinking Ahead: Issues for Adoption of PBEE

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Overview

The promise of performance-based earthquake engineering requires more than development of sound methodologies and analytic tools. Such advances will be left on the conceptual drawing boards unless they are adopted by the engineering profession and are effectively used to inform seismic safety decisions. This on-going study addresses potential issues for adoption and implementation of PBEE based on a review of relevant literature about diffusion of technological innovations and a set of case studies of past engineering innovations.

Diffusion of Innovations

Innovations are either new breakthroughs, or more often, new applications of existing knowledge. In the context of performance-based earthquake engineering, innovations may consist of methodologies that have not been previously widely used, new ways of thinking about performance targets or presentation of analytic results, or technological innovations such as new analysis tools. Widespread adoption of such innovations depends on embracement by engineering firms, day-to-day use by professional engineers, and the willingness of owners and other stakeholders to engage in discussion of desired performance. Also relevant are building officials, inspectors, and other players in building regulatory process. Each of these groups presents both opportunities and obstacles for use of PBEE methodologies and tools. The literature about diffusion of innovations provides insights concerning these opportunities and obstacles. Diffusion scholars find that adoption tends to follow an "S-shaped" pattern as illustrated in Figure 1 for one hypothetical innovation (see Rogers 1995: 11-12). Adoption is initially limited to early adopters and is relatively slow. Once a critical base is established that typically amounts to 10 to 25 percent of potential adopters, the pace of adoption is relatively fast. Then, a point of saturation is reached where reluctant adopters either are slow to adopt or do not act.

The most common explanation for this pattern is what has been labeled the epidemic model of information diffusion (Geroski 2000). According to this, the spread of technology is dependent on the speed with which potential users learn about that technology. Because much information technology rests on personal experiences to evaluate and communicate the benefits of the technology, word-of-mouth communication dominates in the same fashion that many epidemics spread by human contact. In early stages, few learn of and communicate the benefits of the technology. A central element in all of this is a diffusion network made of the interpersonal ties among individuals and firms that serve as information

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flows about innovations. Networks can be comprised of ties with individuals within a firm, among suppliers or competitors, or among professional trade associations or other organized interest groups.

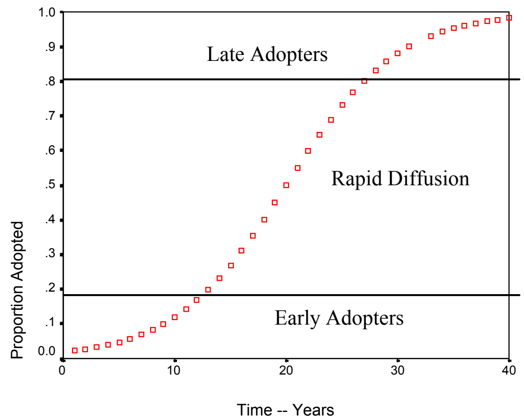

Figure 1. Typical Pattern of Diffusion of Technological Innovations

Factors Affecting Adoption of Innovations

One line of research on adoption of innovations considers characteristics of the innovation itself. Rogers (1995: 208) describes five attributes that affect adoption of innovations: (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability. He defines each as follows. Relative advantage is the degree to which an innovation is perceived as being better than the idea that it supersedes. Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters. Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use. Trialability is the degree to which an innovation may be experimented with on a limited basis. Observability is the degree to which the results of an innovation are visible to others. With the exception of complexity, greater amounts of each of these have been shown to be associated with greater degrees of adoption of innovations. Increased complexity has been associated with lesser rates of adoption.

Another line of research addresses differences among firms that are early and later adopters of innovations. This literature highlights similar characteristics to those of individual early adopters, while also suggesting relevant organizational attributes. As summarized by O'Neill, Pouder, and Buchholtz (1998) in studying adoption of new business strategies, several organizational factors are potentially relevant (more generally see Rogers 1995: 371-404). One is an organization's receptivity to change and learning. Ironically, the research suggests that highly successful organizations tend to be more resistant to change, although there are plenty of counter examples to this general point. Countering the forces of willingness to learn and experiment is the organization drag imposed by bureaucratization and large size. As organizations grow they tend to atrophy, leading to less willingness to try out innovations.

Patterns for Innovations in Earthquake Engineering

The broad literature on diffusion of innovations sets the stage for considering patterns of adoption and implementation of innovations in earthquake engineering. Three such innovations of relevance are seismic isolation (base isolation), load and resistance factor design (LRFD), and performance-based seismic design. Table 1 provides an overview summary of the stages of innovation and adoption, based on secondary accounts of each of these engineering innovations.

Seismic isolation is a concept that is according to Ian Buckle and Ronald Mayes "is perhaps the most innovative development in Civil Engineering since the computer revolutionized structural engineering." Despite this, they comment: "[S]eismic isolation is not yet widely accepted as a valid alternative to conventional seismic resistant design. There is, however, growing evidence, that the methodology is gaining ground" (1990: 196). The pattern for this innovation is very much the s-shaped curve of diffusion scholars. Early versions were contained in patent applications in 1906 in the US and 1909 in England, and in the design of the Imperial Hotel in Tokyo in the early 1920s. It was not until the 1970s, however, with advances in the design of rubber bearings that the approach became technically and economically feasible. This followed with extensive research and application in New Zealand and Japan, with later application in the mid 1980s in the US. By the early 1990s, the innovation had reached the takeoff stage with extensive applications throughout the world. Yet, the uniqueness of the approach and lack of standards until recently left this as less common approach for engineering seismic resistance than that used on most engineered buildings.

Load and Resistance Factor Design (LRFD) is interesting both because it is more of a design methodology (and analytic tools) than engineering fix per se and because it serves as a precursor to performance-based seismic design. Aspects of this approach also date to the early 1900s with the plastic design of steel structures. The conceptual basis was advanced with development of reliability theory in the 1950s and computational advances in the 1950s and 1960s that permitted development of early standards. Development of standards was advanced with a collaboration of academics and industry from the late 1960s until the mid 1980s in carrying out research and developing standards. Standards development using LRFD concepts has been adopted for standard setting for steel, concrete, aluminum, bridge, and wood structures (see Galambos 1998 for an overview of the history of LRFD). Despite the widespread adoption of this approach, Galambos commented in 1998: "The full transition from ASD (allowable stress design) to LRFD will, however, not likely be complete yet for some ten more years" (1998: 2). In writing this, he argued further dissemination requires wider education of practicing engineers about the design approach and development and testing of reliable software for LRFD for a range of structures.

In comparison to seismic isolation and LRFD, performance-based seismic design is in its infancy. The concepts of performance-based codes were advanced by the US Department of Housing and Urban Development with a housing code development program, Operation Breakthrough, that began in the late 1960s and ended in the mid 1970s. However, not until two decades later with the publication of Department of Energy standards for nuclear power plants were the concepts more fully developed and incorporated into practical design for earthquake engineering. The response to the steel frame joint failures in the Northridge earthquake led to wider application of the concepts. As with the development of LRFD standards, the interplay of research and industry was critical for the SAC program as has been the case for subsequent development of guidelines for seismic rehabilitation of buildings. Yet, PBEE is clearly in its infancy as the lessons from the other innovations suggest.

Table 1. Adoption Patterns for Earthquake Engineering Innovations

	Seismic Isolation / Base Isolation	Load and Resistance Factor Design	Performance Based Seismic Design
Earliest version	1906 patent application	1914 Budapest design code	Early 1970s HUD "Operation Breakthrough"
Modern conceptual groundwork began	Late 1970s advances in rubber bearings	1947 rigorous theoretical basis by Freudenthal; 1960s development of concepts of limit states	Evolution of LRFD 1980s into 1990s
Initial modern day application	1979 rail bridge 1982 building Both in New Zealand 1985 Foothills Law and Justice Center, San Bernardino County, CA	1970s advances in reliability analysis and load modeling	Late 1990s repair of moment resisting steel frame joints
Initial US standard or guidelines	1989 SEOAC bluebook guideline 1989 CA hospital guidelines 1991 UBC 1991 AASHTO	1986 AISC specification for steel structures; 8 other codes from 1991 - 1995	1992 – Department of Energy, Nuclear Performance Standards; 1995 – SEAOC Vision 2000 1995 – FEMA 267 SAC guidelines for welded 1997 FEMA 273/274 Seismic Rehabilitation
Current extent of diffusion	Worldwide use of isolation, but small percentage of engineered buildings	Widespread adoption of the design approach in codes and in education	Early stages of methodology and applications

Prospects for Adoption and Implementation of PBEE

Attention to the factors that hindered and facilitated adoption of seismic isolation and LRFD provides insights about future issues for performance-based earthquake engineering innovations. In the case of seismic isolation, key barriers were high perceived costs, uncertainties about the technologies, and lack of standards with which building officials and others could assess structures employing the technologies. In the case of LRFD key barriers were lack of the necessary computational power and computing routines to carry out the necessary calculations, lack of data concerning performance of structures under different loads and their resistance, and reluctance by some of the practicing engineering community given the costs of the required analyses to engage in sophisticated design approaches. For both innovations, the development of standards and guidelines were important in gaining acceptance of the innovations.

Achieving the promise of performance-based earthquake engineering rests both on the successes in engineering research and on the incorporation of research results into everyday practices and decision-making. The translation of research knowledge into practice is not simply a question of disseminating research findings or of developing a set of guidelines or standards. PBEE entails fundamental changes in engineering practice and in decision-making about seismic risks. Bringing about these changes will require concerted efforts and ingenuity in:

- Engaging building owners, civil infrastructure managers, the financial community, public officials, and the public at larger in confronting choices about seismic safety;
- Equipping the design professions to make use of advances in performance-based earthquake engineering methodologies and analytic tools;
- Modernizing regulatory systems to address advances in earthquake engineering;
- Understanding and communicating the societal implications of different choices about seismic safety.

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