

**KNOWLEDGE AND TECHNOLOGY TRANSFER IN  
EARTHQUAKE ENGINEERING: CONSEQUENCE-BASED  
ENGINEERING (CBE) IMPLEMENTATION OPPORTUNITIES  
AND CHALLENGES**

**Three Working Papers and a Bibliography**

**By**

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## **Preface**

This project involved investigating the opportunities offered by, and barriers facing, the adoption of the Consequence-Based Engineering (CBE) paradigm developed by the Mid-America Earthquake Center. The primary intent was to inform the Center's managers, researchers, staff, and others about knowledge transfer processes and implementation considerations. The emphasis was on identifying those factors and processes that could support or inhibit the eventual adoption and use of CBE by practicing engineers and other potential users (i.e., stakeholders) in the region and perhaps nationally.

The work devolved into four principal tasks, three of which resulted in the enclosed Working Papers: (1) Knowledge and Technology Transfer Models, (2) Factors Affecting the Acceptance and Use of CBE, and (3) Recommended CBE Implementation Support Strategies. Each Working Paper contains its own Principal References while the fourth document is the project's Bibliography.

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# WORKING PAPER 1: KNOWLEDGE AND TECHNOLOGY TRANSFER MODELS

## Abstract

This working paper summarizes considerations applicable to knowledge and technology transfer processes and programs by offering four appropriate models for possible application by the Mid-America Earthquake Center (MAE). The models include the Investigator Preference Model, Sponsored Project Model, the Governmental Influence Model, and the Capacity Building Model. Where appropriate, some variations are discussed. Illustrative examples are provided, and in addition, research dissemination and applications methods appropriate to each model are summarized along with typical applications contexts. Finally, an “Application Conflict Ladder” is presented to help users understand how acceptable or unacceptable their implementation proposals might be and how risk reduction proposals might be modified to ameliorate conflict and increase their chances for success.

## INTRODUCTION

Professor Daniel P. Abrams, former Director of the Mid-America Earthquake Center, noted that the Center’s Consequence-Based Engineering (CBE) paradigm “will be of great value in the future to practitioners working with their stakeholder clients to assess their earthquake risk and reduce it through mitigation.” (Abrams, April 2002, emphasis added). CBE is defined to be:

a new paradigm for seismic risk reduction across regions or systems that incorporates identification of uncertainty in all components of seismic risk modeling and quantifies the risk to societal systems and subsystems enabling policy-makers and decision-makers to ultimately develop risk reduction strategies and implement mitigation actions. (Abrams, et. al., March 2002, emphasis added)

Thus, from the very beginning CBE has had end-user needs in mind. This paper is the first of three; it focuses on knowledge and technology transfer models that could facilitate the transfer of CBE’s concepts, methods, and products to various user audiences with the expectation that such users would adopt, adapt, and apply all or significant elements of CBE for their needs.

The March 2002 paper cited above defines practicing engineers as the primary stakeholders because of their need to respond to clients’ needs for earthquake risk mitigation. This working paper expands CBE’s potential user groups to include policy-makers, regulators, building owners, and others because of the broad contexts in which the transfer of knowledge and technology and their applications must occur to reduce risk effectively.

The MAE Center's *Sixth Year Annual Report* recites the challenges facing anyone dedicated to reducing earthquake risk in the central United States. The report provides the framework in which knowledge and technology transfer—including their application—is likely to occur (absent significantly damaging earthquakes in the region in the near to very near future):

Earthquakes in the eastern and central United States are not widely accepted as threats to the civil or private sectors of society though science tells us that they are indeed credible. The most vivid evidence in recent geological times was the sequence of earthquakes over a three-month period of 1811-12 in New Madrid, Missouri...In terms of intensity, [the] three earthquakes in this sequence are ranked in the top ten of those experienced in the last two centuries in the United States...Hundreds of other low and moderately intense earthquakes have been recorded in this region since 1812 indicating that this intraplate seismic region is very much active and that the earthquake threat is indeed real.

Despite the risk, mitigation of earthquake hazards is not a high priority relative to the threat of other more frequent hazards—both natural and man-made. Small to moderate earthquakes...are publicized well for a day, but otherwise are soon forgotten because amounts of damage are usually minimal. The fear of having a major earthquake is not in the minds of the public, most industries or local governments because it has been so long since the last event. (Vol. 1, 1-2)

## **FOUR MODELS**

This section describes four models potentially applicable to CBE's migration from its research and development stages into practice: The Investigator Preference Model, The Sponsored Project Model, The Governmental Influence Model, and The Capacity Building Model. While each model is discussed separately, they actually offer a menu of possibilities which, in various combinations, could support CBE's long-term dissemination, acceptance, and application. These models were derived from a paper published in *Public Administration Review* titled "The Many Meanings of Research Utilization" (Weiss, 1979) and two almost classic studies: *The Utilization of Research: Lessons from the Natural Hazards Field* (Yin and Moore, 1985) and *Getting Research Used in the Natural Hazards Field: The Role of Professional Associations* (Yin and Andranovich, 1987). This working paper was informed further by many of the Principal References for Working Paper 2: Factors Affecting the Acceptance and Use of CBE and the documents listed in the Bibliography that accompanies the working papers.

Each model depends on various mechanisms and processes for the dissemination of knowledge and results flowing from the Center's research activities. Comments are included with the appropriate models about the roles played by these mechanisms and processes. Examples are provided to illustrate each model and some of their variations.

## **Model 1: The Investigator Preference Model**

This model, most well known to the academic community, has the principal goal of advancing knowledge and a secondary goal of educating students who will become future practitioners and researchers. The model is investigator-driven because it is based largely on their intellectual interests, either as individuals or as members of groups, as they seek to understand and explain broadly defined subjects related to improving the seismic safety of the built environment. Investigator interests and preferences prevail, and the process is led by the Principal Investigator. Potential users, if involved at all, are generally passive throughout the research process. It is commonly expected that the initial investigators and other researchers will continue to pursue various aspects of the original research or that users will identify specific related needs that may come back to the research community for further study.

Example: For the earthquake engineering research community, the most familiar approach to securing financing for the Investigator Preference Model is the National Science Foundation's (NSF) unsolicited proposal submission and peer review process implemented under the provisions of the National Earthquake Hazards Reduction Program (NEHRP).

### **Variation: The Guided Preference Model**

One important variation of this model could be called the Guided Preference Model. In this case, for example, NSF solicits proposals to conduct research on specified topic areas. One example offered the opportunity for consortia of university researchers to combine their interests and capabilities into proposals to establish multi-disciplinary centers in earthquake engineering research. Borrowing the concept from its other centers programs, NSF has been supporting the Mid-America Earthquake Center, the Multi-Disciplinary Center for Earthquake Engineering Research, and the Pacific Earthquake Engineering Research Center for several years.

Example: NSF issued a Program Solicitation titled *Multidisciplinary Research into Critical Infrastructure and Related Systems - Mitigation, Preparedness, Response, and Recovery Regarding Disasters and Other Extreme Events*. It encouraged the formation of multidisciplinary teams to address multiple hazards.

### **Knowledge Dissemination and Application**

The principal methods for disseminating and supporting the application of the results flowing from the Investigator Preference Model are via traditional academic avenues, such as publications, conference presentations, and technical meetings and seminars. This model assumes that the existence of new knowledge will lead to further developments and that the utilization of the results will naturally follow but in a relatively diffused manner.

This process depends on creating a context in which new knowledge becomes a widely known resource users can draw upon, ultimately affecting their definition of and the solutions to problems. The diffusion of research results relies on the “percolation” of information through multiple and very different channels, such as the media, academic journals and publications, and interpersonal communications and social networks. The research may not solve immediate problems, but it can foster the development of a pool of information and expertise that users might draw upon to meet their specific needs. Research has shown that professional associations, such as the Earthquake Engineering Research Institute (EERI) and civil and structural engineering associations, play major roles in this process.

## **Model 2: The Sponsored Project Model**

This model is user-oriented from the very beginning because it depends on users to identify and bring their problems to the research community. Users ultimately intend to apply the results (new knowledge or technologies) to solving their problems. According to this model, the knowledge and technology transfer process originates with users first communicating their needs.

Once a conceptual approach and research plan have been agreed to, the follow-on research becomes a search for solutions. The principal assumption of this model is that user-initiated research creates the optimal climate for making and enforcing and implementing the results, but it also constrains investigator interests and preferences. The users’ knowledge and resources (often including funding) are involved at least as much as those of the researcher.

Example: The MAE Center’s *Sixth Year Annual Report* identifies over \$1 million in “Stakeholder Sponsored and Associated Research” allocated to nine projects. Four of the projects are sponsored by federal and state transportation officials, one by a professional group (The Prestressed Concrete Institute), three by the U.S. Army’s Engineering Research and Development Center, and one by the Federal Emergency Management Agency. (Vol. 1, 58)

### **Variation: The Internal Consultant Model**

Some organizations establish internal “consulting” units that must “sell” their services and capabilities to other (often revenue-generating) operating organizational units. In this context, the consulting unit is most likely to operate in a Sponsored Project mode where the “consultant” and/or the “client” jointly identify and define the scope of a particular problem requiring research. The client unit then finances the research needed to better understand or solve its problem, and the consulting unit performs or manages the research. Regardless of whether the internal consultant performs, manages, or in some combination sees that the work is done, the consulting unit is held accountable by the client unit.



Example: The U.S. Army's Construction Engineering Research Laboratory (CERL), one of the Corps of Engineers laboratories that comprise the Engineering Research and Development Center, fits within a broader research context defined by the Department of Defense (DOD) for all of its laboratories. CERL receives its direct research funding through an allocations process that emphasizes basic research and improvement of the technology base related to military construction and facility maintenance. Laboratory management sets research priorities, with preference being given to Army "Strategic Technology Objectives" (STOs) and with requirements that are supported by Army elements. In addition to competing for STO funding, CERL undertakes other projects assigned by DOD, and the lab can generate support via contacts and referrals with the Federal Government, by benefiting from the recognition it receives from completing projects and by demonstrating its capabilities. CERL also can perform research for the private sector, but only if the lab can show that no private sector capability for doing it exists.

### **Knowledge Dissemination and Application**

Both parties benefit in different ways from this sponsored project research experience. This model depends on close interaction between the users and the researchers throughout the research process. The expectation exists that application will begin during or almost immediately after the research is completed.

The researchers often are permitted to present and publish their results in normal academic media, such as those discussed above, and the users apply the knowledge to the solution of their problems. In addition, where users' technical representatives and the involved researchers share similar educational and professional backgrounds, there often are opportunities to co-author or jointly present the research results, but sometimes the technical details are omitted because of proprietary interests.

### **Model 3: The Governmental Influence Model**

This model, little explored in the natural hazards/earthquake engineering knowledge and technology transfer literature, focuses directly on public sector policy and technical research needs. The goal is to affect legislative, administrative, or regulatory governance by providing knowledge and information to support actions taken by public agencies within their domains at any level in ways that cause those being governed to modify their practices and behaviors to increase seismic safety.

#### **Variation 1: The Political Process Model**

This model is overtly political because the knowledge community (earthquake engineering in this case) believes that it can and should affect public policy to achieve desired seismic safety goals. The advocacy method may vary significantly (e.g., single spokesperson, formal or informal committee, professional or trade association, coalition of shared-interest groups), but each seeks to get seismic safety proposals on the political agenda so they can be considered. This can be a very arduous and complex undertaking,

but mobilizing the research and practitioner communities can, if political access is achieved, be a direct and potentially very influential knowledge transfer mechanism.

Example: California's legislature established the Joint Committee on Seismic Safety in 1970 to examine what could be done through research, practice, and public policy to lessen the state's earthquake risk. This action was triggered by a 1968 university publication, *Earthquake Hazard in the San Francisco Bay Area: A Continuing Problem in Public Policy*. The February 9, 1971 San Fernando earthquake opened the well-known "window of opportunity" and the Joint Committee sponsored several successful landmark seismic safety laws.

### **Variation 2: The Regulatory/Administrative Model**

The executive branch of government ("the bureaucracy") interprets and applies the laws it is given to enforce (and sometimes helps craft them before enactment). Often, great latitude is given to the administering organizations because the basic legislation provides only the "charter." Thus, once legislation is adopted, the interested stakeholders shift their attention and energies to the less visible but often more important long-term and continuing implementation (i.e., rule making and enforcing) process. Access to implementation decision-making and administrative processes continues through often informal professional relationships (e.g., engineer to engineer), formal hearings required as part of the rule adoption process, membership on advisory and appeals boards, and via other similar mechanisms. Most practicing engineers are very familiar with such processes associated with the adoption and implementation of building codes.

Example: California's Office of Statewide Health Planning and Development is charged with enforcing the 1994 law that requires the seismic safety of pre-1973 hospitals to be addressed. The Seismic Retrofit Unit of the Facilities Development Division adopted and is enforcing regulations (known as "Division III-R") that apply to all existing acute care hospital buildings. Some of the issues that have arisen during the administrative process include the schedule for compliance, acceptable compliance plans, and financing.

### **Knowledge Dissemination and Application**

The direct involvement of researchers and practitioners in overtly political processes virtually assures knowledge and technology transfer, at least in addressing the specific policy and technical issues under consideration (i.e., "on the agenda"). In this case, researchers and practitioners both act as "translators" by framing proposed legislation or regulations (which can be and often are far more technical) that will be adopted and implemented by legislative and regulatory or administrative organizations.

Feasibility, however, becomes a major criterion in achieving effective risk reduction through governmental processes because of the mobilization of stakeholders and advocacy coalitions. Thus, it is common to find compromises being made to accommodate less than supportive—but other influential—interests.

## **Model 4: The Capacity Building Model**

Although knowledge transfer and learning occur within the context of each of the above models, it is important to focus specifically on the Capacity Building Model. The model usually is associated with formal education processes, such as the MAE Center's student researcher activities and the curricula of the member universities, but there are variations such as continuing education opportunities or requirements related to professional licensing, intergenerational mentoring in an on-the-job setting, and a more diffused "social interaction" model.

Where seismic safety subjects are built into college and university curricula and related activities, students are exposed to issues of earthquake risk. For example, the MAE Center's *Sixth Year Annual Report* notes that:

The...Center is preparing its students for the future generation of earthquake scientists and engineers through a number of activities which promote student involvement in earthquake research. Students are eligible to apply for a center-wide Certificate in Earthquake Science and Engineering by taking courses...[A] Consequence-Based Engineering Institute, first held at Texas A&M University over a six-day period, gave students from the center institutions to learn from diverse, interdisciplinary faculty on topics ranging from seismology to social science. (Vol. I, 7)

### **Variation 1: The Continuing Education Model**

Many states require licenses to practice in various fields, and some have instituted continuing education requirements as a condition of re-licensing. Also, many professional organizations have continuing education requirements to ensure that their members maintain an acceptable skill level. These mechanisms play important roles in knowledge transfer and in maintaining acceptable standards of practice, helping to avoid an often heard observation that only a relatively few members of a particular profession voluntarily take advantage of professional development opportunities.

Example: The University of California at Berkeley offers through its extension program a Certificate in Earthquake Engineering for successful completion of 210 hours (14 units) of instruction. The program offers instruction in the scientific, engineering, legal, regulatory, and policy-shaping aspects of earthquake engineering, "enabling you to function more effectively and to progress in your career." (1)

### **Variation 2: The Mentoring Model**

EERI's oral histories clearly demonstrate the important roles that on-the-job mentoring plays in knowledge transfer and professional development. In California, for example, some practicing engineers incorporated earthquake-resistant design considerations into their projects beginning after the 1906 San Francisco earthquake, but especially after the 1923 Kanto, Japan event, and especially after the 1925 Santa Barbara and 1933 Long

Beach earthquakes. This was a time when recommended design provisions were published, a few local building codes containing earthquake design requirements were adopted, and the first state seismic safety laws were enacted: the “Riley Act,” which set minimum standards for buildings and the “Field Act,” which set standards for new public school buildings.

These oral histories show how younger engineers who were fortunate enough to work for leaders in the emerging earthquake engineering specialty benefited from the knowledge and experience they gained—and later maintained—in incorporating earthquake resistant design features into their projects. Many of this “second generation” earthquake elite refer in their oral histories to the importance of the on-the-job mentoring processes.

Example: The importance and lasting influence of mentoring was reflected in a recent (March 14, 2003) letter to the PI from a retired structural engineer who said, “...it was nostalgic for me to see that you gave some credit [in an article] to my former boss and mentor, Reuben Binder. I was his assistant from 1947 until 1953...” (Preece to Olson), and in an e-mail message (March 25, 2003) that noted, “Rube Binder hired me, out of the University of Illinois...He was...a true professional, and remains a role model for me. Largely because of him, I have retained an interest in technologic progress, especially in seismic matters...” (Dooley to Olson)

### **Variation 3: The Social Interaction Model**

This non-linear model emphasizes the diffusion of knowledge through informal, frequent, and often one-to-one communications. Information is sought from a variety of sources and exchanged through often lengthy discourses between those involved. The openness of communications facilitates the use of new knowledge and technologies as users and researchers become aware of each other’s needs, capabilities, and limitations as they develop collaborative relationships.

This model assumes that knowledge and technology transfer will be most successful when there is frequent contact between researchers and users through facilitating organizations and mechanisms such as the MAE Center’s Stakeholder Advisory Board or professional associations such as local chapters of EERI or the American Society of Civil Engineers (ASCE). This model also assumes that users will have a greater willingness to accept and use new information or technologies that are received from familiar and trusted contacts.

Example: In 1980, California’s Governor appointed a Task Force on Earthquake Preparedness. One of its committees (the Finance, Insurance, and Monetary Services Committee) was composed of often competitive industry members and also regulatory representatives from the state government. The committee defined a shared concern: the stability and operability of data processing centers in earthquakes. This led to a collaborative effort with earthquake engineering faculty members and practitioners to develop what became a jointly financed technical manual, *Data Processing Facilities: Guidelines for Earthquake Hazard Mitigation*.

## **Knowledge Dissemination and Application**

The Capacity Building model and its variants share a common goal: the development of expertise and the application of knowledge through education and close collaboration, often intergenerational, that serves to sustain the earthquake engineering community. The close professional relationships formed particularly via the Mentoring and Social Interaction variants often span many years, are mutually reinforcing, and are efficient because they eliminate the “getting acquainted and up to speed” processes that are common to new relationships. Numerous examples exist of how peer groups can assemble rapidly, achieve understanding and consensus, and adopt and advocate improved earthquake hazard mitigation measures.

### **APPLICATIONS CONTEXTS**

No one knowledge and technology transfer model will be effective in reducing earthquake risk in the central United States. Rather, several—perhaps all—could be combined in various ways over different time periods to reach identified audiences so the targeted users learn about the risk and modify their behaviors to give greater attention to—and invest in—earthquake risk reduction activities. Regardless, any combination of models will be implemented in two temporal contexts: prospective and retroactive; and four different social contexts: attrition, informal/negotiated, voluntary, and mandatory/regulated. Each of these contexts is characterized by differing levels of “Application Conflict,” the management of which must be considered when the models are used to define applications strategies.

#### **Two Temporal Contexts**

Hazard mitigation occurs within two temporal contexts: (1) prospective and (2) retroactive. In general, prospective programs address the future and are easier to adopt and implement. Retroactive programs to correct past deficiencies are much more difficult. For example, incremental changes to building codes that apply to new buildings can be incorporated into new designs and enforcement mechanisms relatively easily and inexpensively, but laws or codes that require the strengthening or replacement of existing buildings are difficult to enact, complicated and often controversial to implement, and can be costly in terms of construction and social costs (e.g., dislocation of tenants, loss of rental income). For these reasons, most mitigation programs are prospective, and if enacted at all, retroactive requirements often follow decades later (e.g. California’s law setting standards for new hospitals was adopted in 1973, but it was not until 1994 that the law was amended to deal with pre-1973 hospital buildings.)

#### **Four Social Contexts**

The success of all earthquake risk reduction measures (i.e., actions taken to reduce future losses) depends on the contexts in which such actions are taken because they establish the boundaries or parameters that govern acceptability, feasibility, and accountability.

### **Context 1: The Attrition Context**

Given that existing non-earthquake resistant buildings pose the greatest life risk, and “that a regular building replacement process is ongoing in virtually every jurisdiction in the United States,” the turnover slowly but steadily can (but may not) lead to a safer built environment:

[The normal attrition process] directly affects the earthquake-vulnerable building problem...For attrition to have a positive effect on seismic rehabilitation, a jurisdiction must exhibit strict adherence to current codes containing seismic provisions appropriate for its seismic risk zone. The idea is to prevent the construction of new buildings of the types previously identified as earthquake-vulnerable...while the normal process of building replacement slowly reduces the number of existing earthquake-vulnerable buildings.

It might be useful to think of the earthquake-vulnerable buildings as a “stock and flow” problem. At any one point in time, a jurisdiction will have a certain number of buildings that present life-safety threats...That is the “stock” of the problem. Simultaneously, normal attrition processes...are reducing the number of vulnerable buildings, which is the “flow out”... (Federal Emergency Management Agency {FEMA}, 10-11).

### **Context 2: The Informal/Negotiated Context**

This approach is more common than is often appreciated. In this context, “building officials often try to reach agreement with owners involved in building rehabilitation. Such negotiations can be based on authority granted by a local ordinance or can be conducted as part of a building official’s administrative responsibilities.” (*Ibid.*, 14)

Example: Provo, Utah “achieves seismic rehabilitation of existing buildings by negotiation with building owners. No mandatory requirements exist...[but] the building department applies its negotiated informal approach only when a significant improvement or change occurs to one of these [unreinforced masonry] buildings...” (*Ibid.*, 14)

### **Context 3: The Voluntary Context**

The voluntary approach to earthquake risk reduction depends on owners’ understanding and acceptance of risk and their decisions to invest in mitigation to protect their assets. As the above FEMA publication notes:

Not adequately appreciated is the number of buildings that have been and are being seismically rehabilitated by their owners without compulsion by local building officials. Such rehabilitation may focus on the seismic aspect alone or may feature seismic aspects as part of a larger remodeling effort. Either way, it is essentially a private or at least an owner-driven and, therefore, a low conflict

process...Under this [program], owners decide...to seismically rehabilitate their structures and approach building officials for permits and perhaps even for assistance or advice...The building official then permits owners to rehabilitate the buildings on their own.” (Ibid., 11)

Example: In Clayton, Missouri school district officials needed a voter-approved \$6.6 million bond issue to finance new or replacement construction and a range of school improvements. These officials recognized the earthquake threat in the New Madrid area but understood equally well that the public perception was low. By “packaging” seismic considerations as one of the five “compelling and immediate needs” inside an overall bond argument...the Clayton School District won the bond election and was able to carry out nearly \$3 million of seismic rehabilitation projects by “strengthening portions of existing schools.” (Ibid., 14)

#### **Context 4: The Mandatory/Regulatory Context**

As its title suggests, this approach relies on forceful governmental intervention to reduce seismic risk. Consequently, its potential for conflict is very high because the burden falls almost entirely on building owners. According to the same FEMA publication, the “debate entails extended technical arguments...the direct cost question...the cost incidence question...and the indirect cost considerations. Battles also are joined on scope (what buildings), priorities (which buildings first and why), and pace (how fast).” (Ibid., 17)

Example: Following the March 10, 1933 Long Beach earthquake, the city amended its building code to effectively prohibit the construction of new unreinforced masonry buildings, hundreds of which suffered serious damage in the earthquake. However, the pre-1933 buildings continued to exist, and major damage to the same types of buildings in nearby San Fernando on February 9, 1971 led Long Beach to reconsider its “existing buildings” problem. On June 29, 1971, the Long Beach City Council passed a specific ordinance to abate the hazard posed by unreinforced masonry buildings. Eventually, almost 900 pre-1934 masonry, concrete, or steel buildings were either seismically rehabilitated or demolished. (Ibid., 18)

#### **An Application Conflict “Ladder”**

As might be expected, application conflict tends to vary from lowest in the Attrition Context to the highest in the Mandatory/Regulatory Context. The level of conflict has major implications for successful knowledge and technology transfer because the degree of conflict has substantial influence on the risk reduction goals sought, the methods proposed, and the implementation mechanisms needed to achieve success.

The following “Conflict Ladder” portrays these relationships from lowest to highest conflict:

- Step 1: The Attrition Context= Lowest Conflict
- Step 2: The Voluntary Context = Very Low Conflict
- Step 3: The Informal/Negotiated Context = Modest Conflict
- Step 4: The Mandatory/Regulatory Context = Highest Conflict

There are, however, ways to ameliorate or modify the extent of application conflict by designing the chosen risk reduction strategy to minimize conflict, thereby helping to assure the strategy’s adoption and implementation. For example, a mandatory program requiring owners to strengthen or replace unsafe unreinforced masonry buildings by a specified near future time (e.g., 10 years) using stringent standards and enforcement processes would most likely be a Step 4 effort. However, should the governing jurisdiction adopt a longer time for compliance (e.g., 25 years), require only minimal modest life safety improvements, and provide some financial incentives (e.g., property tax reductions, low interest loans, matching grants) the program could move up to Step 3, increasing the measure’s chances for successful adoption and implementation.

## CONCLUSION

This Working Paper is the first of three, and by addressing a few general considerations relevant to the MAE Center’s paradigm, Consequence-Based Engineering, the paper offers several knowledge and technology transfer models that could be appropriate for disseminating and promoting CBE’s application, and it summarized four applications contexts in which CBE might be used to promote earthquake risk reduction in the central United States—and possibly other low to moderate seismic risk areas.

The other two Working Papers address Factors affecting the acceptance and use of earthquake engineering research and recommended long-term knowledge and technology transfer strategies for the MAE Center’s consideration as CBE moves from research into practice.

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## **WORKING PAPER 2: FACTORS AFFECTING THE ACCEPTANCE AND USE OF CONSEQUENCE-BASED ENGINEERING (CBE)**

### **Abstract**

This working paper describes factors that could affect the acceptance and use of research, Consequence Based Engineering (CBE) in this case, by various stakeholder groups. Depending on the context or situation, or slight changes in them, many factors could be either barriers or opportunities. A few broad considerations related to earthquake engineering knowledge and technology transfer are presented, and four categories of factors are defined. Each factor is described briefly, potential barriers affecting its application are noted, and possible tactics for overcoming the barriers are offered.

### **INTRODUCTION**

This working paper identifies and characterizes a number of strategically relevant factors (i.e., barriers and opportunities) that could be important to the eventual acceptance and application of Consequence Based Engineering (CBE), which is seen in this context as an earthquake engineering innovation. The discussion of the factors also includes potential tactical methods for overcoming the barriers. May (2002) stresses the importance of going beyond promises of new technologies by noting that:

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. Recognizing this, it is important to remember that the adoption of new methods is not automatic. The availability of a methodology or tool does not guarantee that it will be effectively employed. In short, it is a long way from the research laboratory to actual practice. (1)

Other researchers have reviewed the diverse literature on the social diffusion of innovations, and they and others have drawn lessons from this literature applicable to earthquake engineering innovations. Taylor and his colleagues found a common trait associated with all “seismic evaluation approaches” in that all of them “involve combining estimates of earthquake hazards and vulnerabilities of systems and their components to assess expected losses and prospective reduced losses through seismic risk reduction measures.” (30) Focusing specifically on CBE, this paper, coupled with the Principal Investigator’s experience, further refines the earthquake engineering innovation information so it can be considered as CBE moves from research and testing into prospective adoption and application (i.e., “use”).

In addition to *A New Engineering Paradigm: Consequence-Based Engineering*, prepared by the MAE Center’s leaders (Abrams, et. al), several other recent studies, articles, and reports provided thought-provoking information that is directly relevant to CBE’s future. They include *National Earthquake Probabilistic Hazard Mapping Program: Lessons for Knowledge Transfer* (1996); *Overcoming Barriers: Lifeline Seismic Improvement*

*Programs (1998); Implementation Issues for the SAC Project Guidelines: Report on the Social, Economic, Policy and Political Issues Workshop (1998); Overcoming Obstacles to Implementing Hazard Mitigation Policies: Stage I Report (2001); Organizational and Societal Considerations for Performance-Based Earthquake Engineering (2001); Societal Perspectives about Earthquake Performance: The Fallacy of “Acceptable Risk” (2001); Earthquake Resilience Through Mitigation: A System Approach (2002); Barriers to Adoption and Implementation of PBEE (2002); and Public Hazards Education: The State of the Art (2003).*

Following a few general considerations and lists of barriers identified by others, this working paper focuses on potential non-technical—especially potential user-CBE interface—barriers, which are grouped as follows: Understanding Risk and Accepting Potential Losses, Stakeholder Capacities to Use CBE, Supporting Stakeholders, and Further Considerations. The factors are deemed important to CBE’s eventual adoption and application. Each factor is briefly discussed, the potential barriers each poses are presented, and possible ways to overcome the barriers (or to optimize the opportunities) are summarized. CBE’s more technical issues are being dealt with by other MAE Center researchers who are responsible for developing various CBE components.

## **KNOWLEDGE AND TECHNOLOGY TRANSFER CONSIDERATIONS**

Several broad considerations related to knowledge and technology transfer processes should be recognized before discussing the more specific factors associated with the adoption and application of CBE in Mid-America. The considerations are:

1. CBE is an earthquake engineering innovation, and its introduction and use will be governed largely by the “rules” (i.e., customs, values, needs, anticipated benefits, learning needed, willingness to change) affecting the adoption and implementation of innovations into particular societal and decision-making contexts.
2. The contexts themselves largely will determine the extent to which CBE will be adopted and applied in whole or in part. Private engineers, for example, might use CBE’s risk analysis capabilities as an information tool to help their clients understand the clients’ exposure, differing impacts of earthquakes on the clients’ structures, and the design standards and techniques to use to meet society’s or their clients’ performance needs when designing and constructing new facilities or rehabilitating existing ones.
3. The effective communication of risk is an essential pre-condition and continuing need to support the adoption and application of any risk reduction strategy, especially where periodic events are punctuated by long intervals, as is the case in the central United States.
4. Unless triggered by a notable event, such as a major regional earthquake, the adoption and application of an innovation, CBE in this case, will take time, perhaps a decade or more.

## **BARRIERS SUMMARIZED**

This paper intends to help overcome what Alesch and Petak (2001) define as a fundamental obstacle: “an inadequate understanding of the barriers and disincentives associated with implementing earthquake hazard mitigation technologies and of how to overcome them.” (2) Several of the reference documents identify potential barriers that could be important to CBE’s long-term adoption and application in the central United States. For example, the MAE Center’s leaders identified 10 related to the technical development of CBE, including:

1. Standard procedures need to be developed for rapid estimates of consequences from approximate definitions of systems.
2. A standard approach needs to be developed for identifying what consequences are acceptable for various stakeholders. A study of acceptable consequences for a number of different stakeholder systems and scenarios is needed to gain perspective on how practitioners should resolve with their stakeholder clients what their acceptable consequence levels may be, and how much redefinition of these levels may be possible.
3. Basic studies of decision making need to be done to identify: (a) how various stakeholder groups react to anticipated consequences, (b) to what extent a stakeholder will be willing to invest in parameter refinement and/or system intervention to reduce consequences, and (c) what types of system intervention are attractive to stakeholders for reducing consequences of earthquake and other hazards.
4. Tools need to be improved for estimating seismic hazards in regions where earthquake records are sparse. Hazard maps and synthetic ground motions are needed to refine seismic hazard estimates from current information. Basic knowledge of source, path and site effects for infrequent, high consequence earthquakes needs to be improved for development of ground-motion simulations. Better information is also needed for improvement of ground-failure modeling in such regions.
5. The most relevant parameters of regional inventory information, essential to precise loss assessments, need to be identified. New survey techniques based on advanced technologies need to be developed so that inventory data can be collected quickly and inexpensively, and yet be the bases for precise consequence estimates.
6. New structural analysis tools need to be developed for estimating seismic response of a wide variety of existing and rehabilitated construction systems. Simple, yet accurate response estimates are needed to generate fragility or vulnerability functions for categories of construction types.
7. Approximate vulnerability functions representing categories of typical construction types need to be developed for quick estimates of losses across stakeholder regions.

8. Social impact assessments need to be studied for various stakeholder regions to understand how to incorporate societal vulnerability within computational models.
9. A highly capable, consequence visualization module needs to be developed exploiting recent advancements in information technology to synthesize information and data on the seismic hazard, regional inventory, seismic response and vulnerability and socio-economic impact. This module is the central engine of the CBE paradigm, and is essential for running a number of quick, but precise, iterations depicting consequences across a region.
10. Interventions to minimize consequences across specific stakeholder regions need to be developed. Such measures may include new technologies for rehabilitation of vulnerable construction types identified as critical to system performance, re-routing of network systems or re-management of land use across particular stakeholder regions. (Abrams, et al., 8-9, emphasis added)

In addition to and complementing the above list, and calling it a “formidable and daunting list,” Taylor and his colleagues (1998) in their monograph, *Overcoming Barriers: Lifeline Seismic Improvement Programs*, identified 18 barriers affecting the adoption implementation of earthquake risk reduction measures in “lifeline” organizations. Many are applicable also to CBE’s future acceptance, adoption, and implementation, especially because of the importance of lifeline systems in the central United States.

The list includes “controversial science and engineering; unclear communication of science and engineering; irrelevant science and engineering; denial of low-probability events; the low cost-effectiveness of seismic risk reduction measures; the high volatility of seismic risk reduction measures; diffuse benefits (who becomes safer) [and] clear costs (developers and owners); high initial costs of earthquake risk reduction measures; low priority of low-probability risk reduction measures; lack of time to investigate complex issues; the proactive nature of earthquake mitigation measures; little organization to seismic safety advocacy; the contrast between actual and perceived earthquake threats; fragmentation of responsibility for seismic safety; unresolved interdisciplinary differences on seismic hazards; lack of diffusion of information between levels of government and among units of government at the same time; financial disincentives from (a) federal disaster relief policy and (b) insurance, lending, and bond underwriting that fails to differentiate poor and good earthquake risks; and few damaging earthquakes.” (4-5)

May (2002), based on his analysis of innovation and adoption patterns associated with seismic isolation, Load and Resistance Factor Design, and Performance-Based Seismic Design, identified several barriers to the adoption and implementation of the three earthquake engineering innovations. They are “Overcoming uncertainty about the methodology and its benefits; Addressing concerns about the costs of employing the methodology; Addressing the complexities of the methodology and of required analysis procedures; Legitimizing the methodology; Establishing comparative advantage; [and] Facilitating early adoption.” (33-35)

Many of the applicable issues raised by the MAE Center’s leaders, Taylor and his colleagues, and May are addressed singly or in combination below. The intent is to understand how these barriers might apply—and be overcome—within the emerging CBE applications context.

## **POTENTIALLY INFLUENTIAL FACTORS**

Addressing and resolving many of the issues noted above and in the following discussions of four categories of factors extend well beyond the MAE Center’s research foci and capabilities. Consequence Based Engineering, the MAE Center’s intellectual and conceptual contribution to systems risk analysis, loss estimation, and mitigation intervention, means that the Center must become and remain an active member over the long term in another system—the “stakeholder adoption and application system.”

Stakeholders are defined as “groups or individuals making decisions to invest in a particular intervention to mitigate possible earthquake losses. Examples...include insurance executives, city managers, state highway officials, and owners of large building stocks.” (Abrams, et al., 1)

Alesch and Petak in their study of earthquake risk reduction public policy innovations discuss the complex relationships inherent in the pluralistic stakeholder community by calling it a “web that resembles a network more than a rationally designed, sequential process,” leading them to note that:

Successful policy implementation presumably requires successful implementation by each constituent element in the “implementation network.” Each constituent actor has a different set of responsibilities and tasks, so evaluating the implementation process requires separate analysis of how each of the elements performs its role...One can also think of policy implementation as the sum of the actions taken by various participants in a complex process leading to desired risk reduction measures in place in real organizations...We find it useful to think of implementation processes as factor rather than fixed and as existing within complex, shifting, and relatively ephemeral networks of relationships among governments at various levels and private organizations. (24)

The nature of the factors themselves may evolve over time, and their particular characteristics, presence or absence, strength or weakness, or the effects on them of unforeseeable internal and external influences are important to CBE’s future as a regional earthquake loss reduction decision support tool.

## **Category 1. Understanding Risk and Accepting Potential Losses**

### **A. Communicating Earthquake Risk Information.**

Research and experience in the hazards and emergency management fields have shown, for example, that repetition is important, multiple channels of communication are needed, information tailored to the understanding and needs of target audiences is necessary, sources of risk information must be trustworthy, issue or advocacy leaders are needed, visible and positive examples contribute to taking action, and the validation of the information with peers and broader social groups is important. Effective risk communication is so important to the entire seismic safety process that Alesch and Petak state as one of their “Preliminary Implementation Conclusions” that “If a basic obstacle to taking precautions is an inaccurate assessment of risks by the target organization, then the hazards professional, if he or she expects to have a significant impact, must provide that organization with a clear, compelling statement of the risks to the organization.” (57)

Potential Barriers. First, institutions may be unable or unwilling to financially support the continuing long-term risk communications programs that will be needed. Second, people and organizations that do not share the same perception of the risk could mount informational efforts to counter the earthquake community’s “scare tactics.” Third, well publicized differences in opinion among “equally competent experts” create doubt and could lead to discounting the risk and not taking action by large parts of the stakeholder community. Fourth, and assuming the risk communication process is effective, is the almost imponderable barrier of competing relative (and more immediate) priorities, especially associated with a “remote” threat.

Overcoming Barriers. First, since CBE is stakeholder-focused and not designed to inform the greater public, it will be very important to tailor CBE materials and information dissemination activities to key stakeholder groups so they will change their behavior in ways that commit to earthquake risk reduction. This communication effort will have to be sustained so the risk remains a salient issue and interest in CBE does not atrophy over time. Second, stakeholders will need customized materials to support their efforts. Third, supplemental personal relationships are very important in moving stakeholders from information recipients to activists during the early confirming, adoption, and advocacy coalition-building stages of risk reduction activities.

Organizations such as the Center for Earthquake Research and Information (CERI) at the University of Memphis and the Central United States Earthquake Consortium (CUSEC) play key interface and knowledge transfer roles. They and other state and local groups should become the “core” of a CBE users and technical assistance network with MAE Center researchers providing the intellectual resources.

## B. Translating Potential Losses into Decision Support Data

CBE's professed goal is to influence stakeholders' decisions, and at an aggregate level, CBE will provide a path for stakeholders to follow when they consider CBE's implications for their own facilities and assets. Thus, flowing from the need to provide useful risk information on a sustained basis is the corollary need to "translate" and deliver potential loss information in stakeholder-friendly formats and venues in sufficient detail to provoke its internal consideration because "risk reduction measures are more likely to be implemented when organizational decision makers make a conscious link between the potential hazardous event and likely effects on them and their businesses." (Alesch and Petak, 57)

Petak (2002) reinforces this point by stating that:

the low probability earthquake with its high consequences is the problem and risk reduction mitigation the solution[;] however, an opportunity for adoption of the mitigation solution with stakeholder support is required before implementation of risk reduction measures can occur...

individual organizations must recognize and understand the problem and its potential consequences for their organizations, assess risk reduction alternatives, and obtain stakeholder support for [the] selection and implementation of mitigation alternatives.

In general, organizational decision makers are responsible for actual implementation of mitigation policy and regulations, either through voluntary actions or under force of law. Since much of the built environment was constructed before the current knowledge about earthquake loss mitigation was developed, and because new rules/regulations are difficult to enforce retroactively, acceptance and implementation will be highly dependent on the degree to which organizational leaders have been informed and involved... (8, emphasis added)

Potential Barriers. First, the scale of the loss information may make it difficult to disaggregate the data into sufficient detail so stakeholders can apply the information to their systems, structures, and facilities. Second, even if loss and consequence data can be translated into sufficient detail, stakeholder representatives may be unable to secure a place on their organizations' decision agendas. Third, most stakeholders probably will need additional geotechnical and earthquake engineering studies of their particular facilities beyond what CBE is capable of providing.

Overcoming Barriers. First, stakeholders could help with the loss and impact translation function by working with qualified earthquake engineers to interpret the data for application in the stakeholders' individual situations. Second, internal stakeholder advocates need to be identified so that potential losses and impacts can compete for decision agenda space. Third, the inclusion of stakeholder representatives in the Memphis Test Bed project can provide a model for future involvement. Fourth, stakeholders may have to pay for detailed site and facility specific studies.



## **C. Determining and Reassessing “Acceptable Consequences”**

While CBE will provide hazard, loss, and consequence (i.e., impact) information, determining the bounds of “acceptability” largely will be judgmental. The stakeholders’ judgments about acceptable consequences will be influenced by a variety of non-technical factors and other competing demands for limited resources. Stakeholders can interpret loss information and establish some parameters for what is acceptable to each of them, with wide variance among the stakeholder population. The subject of acceptable consequences will be examined further in Year 7 (2003-2004).

Potential Barriers. First, stakeholders will be concerned primarily with losses to their assets, and while they may understand the seriousness of the more widely distributed consequences of their losses, stakeholders can only directly affect what they “own.” Second, the definition of acceptability varies and can change suddenly depending on circumstances, such as locally damaging earthquake, when the wider public interprets the losses as “unacceptable” (and someone should be blamed for ignoring the earthquake threat).

Overcoming Barriers. First, the dynamics associated with the moving definition of acceptability means that stakeholders periodically must reexamine their vulnerabilities and their acceptable consequence judgments so they remain current and defensible. Second, adopted and implemented risk reduction measures ought to be well documented and regularly noted as positive steps taken to reduce stakeholder vulnerabilities so when losses are incurred they can be explained within a context of a longer term mitigation program. Third, for decision-making and informational purposes, acceptable consequences should be framed as achievable “safety goals.” This is more than semantics; while the goals may remain almost indefinitely, progress toward achieving them can be measured and reported.

## **Category 2. Recognizing and Dealing with Stakeholders’ Capacities**

### **A. Applying CBE in Fragmented Stakeholder Domains**

Stakeholders are not the same, they are numerous, they represent all sectors, and they have differing priorities, mandates, and resources. While CBE provides a holistic approach to understanding the region’s earthquake risk, potential consequences, and possible mitigation interventions, each stakeholder has its own domain in which it fulfills its responsibilities. For example, buildings are owned by multiple owners (some of which may be absentee investors); road, highway, freeway systems (including the trans-Mississippi River bridges) are governed by local, state, national, and possibly special district authorities; and practicing engineers work in each of these varied contexts, usually on individual projects.

Fragmentation is characteristic of the United States, leading Petak (2002) to point out the need for developing interorganizational links (i.e., collaborative relationships) with others so an advocacy coalition is formed that spans fragmented stakeholder domains:

Building bridges between agencies, organizations and individuals is intended to build understanding, support, and capacity. Earthquake mitigation advocates, agency heads, and the owners and operators of organizations need to develop collaborative efforts within a framework of understanding. That requires a process that spans hazard, political, generational, and ownership boundaries.

Implementation requires a willingness among individuals, business organizations and governmental agencies to take appropriate actions to reduce the risks of catastrophic loss to their property. The critical questions will involve debate about the extent to which potential future economic and social costs be weighed against the benefits of immediate implementation of earthquake mitigation policies...(10)

Potential Barriers. First, few, if any stakeholders, have the breadth of responsibility to fully apply CBE's concepts and methods in their totality. Each stakeholder, however, can see where its concerns fit into the broader picture. Second, given this fragmentation, organizational mechanisms to foster collaboration and coordinate activities may or may not exist. Third, decision-making also is fragmented and will vary considerably between government and private sector assets owners. Fourth, and more as a reminder, a significant barrier could be opposition to doing anything more to manage the region's earthquake risk.

Overcoming Barriers. First, stakeholders belong to, or should be encouraged to participate in, shared interest organizational networks like professional associations, multistate committees, and others where each can identify its mitigation roles and take responsibility within its domain for achieving total system resilience. Second, MAE Center researchers should be ready to advise and assist stakeholders in addressing their respective risks.

## **B. Developing Organizational Capacity**

Organizational capacity is one of the most frequently referred to factors that will be important to CBE's adoption and application. Capacity encompasses the stakeholders' abilities to institutionalize CBE by providing learning and training, securing competent technical expertise, investing in the applications software, and having the wealth to address a potentially major but uncertain problem. Taylor and his colleagues, when examining lifelines organizations, had two relevant observations regarding capacity:

Organizations and the individuals undertaking a[sic] seismic improvement programs have exhibited a strong sense of ownership of their programs, which are tailored not only to the specific facilities and system in question but also to the needs, capabilities, and circumstances of the organizations themselves...In general...seismic improvement programs are enhanced when the organization undertaking them is financially robust. (57-58)

Potential Barriers. First, not all stakeholders will perceive the risk equally, and this will affect their willingness to invest intellect, time, and financial resources to applying CBE within their respective domains. Second, capacity-building may have to compete with other perceived needs and priorities. Third, some organizations, while perhaps interested in CBE, will not act until they confirm its value, see others (i.e., early adopters) use the approach, or determine that using CBE will maintain or provide a comparative advantage.

Overcoming Barriers. First, prospective CBE users must see value in acquiring the “CBE package.” Second, the adopting organizations must have the resources and be willing to commit them to become CBE-competent. Third, Center researchers, committed stakeholders, and early adopters should demonstrate leadership by “showcasing” and publicizing CBE’s applications. Fourth, this “leadership group” should proactively explain, especially to their peers, how CBE has helped the early adopters and initial leaders better understand and manage the earthquake risk to their assets.

### **C. Focusing on Engineers as “Change Agents”**

While CBE focuses on affecting risk reduction decisions, the practicing engineer is seen as the key link between CBE and the stakeholders: “CBE technologies provide an engineer with the tools, approach and application steps needed to communicate possible consequences, and how they vary with different system alterations, to their respective stakeholder clients in such a manner that the benefits of mitigation actions can be clearly envisioned.” (Abrams, et al., 1-2)

Although he was addressing another earthquake engineering analysis method, May (2002) offered the CBE-relevant thought that:

The engineering profession will be required to fulfill a broader consultative role in explaining the stakes involved in making choices about earthquake risks, the relevant choices, and advice about the implications of those choices. These choices, in turn, will require building owners, investors, public officials, and other stakeholders to think differently about decisions regarding the management of earthquake risks. (25, emphasis added)

Taylor, et al., concluded from their study of lifeline organizations that:

What unites the organizations...who successfully implemented seismic risk reduction programs was the desire of engineers first to ensure system, subsystem, and individual component performance by incorporating technological advances and [convincing] executives thereafter to support the continuing development of reliable lifeline systems which would limit monetary losses due to earthquake[s] and which could be brought back on line quickly after earthquakes to ensure the resumption of profitable service. (11, emphasis added)

A common characteristic was the existence of knowledgeable engineers who purposefully integrated seismic risk considerations into engineering operations over long periods of time [several decades]. (18, emphasis added)

Potential Barriers. First, the typical practicing engineer is “project driven.” While CBE may help her or him understand and explain potential losses and their consequences, it will be the project’s design and construction needs that dictate engineering parameters. Second, practicing engineers regularly face the client-asked question: Am I required to include earthquake risk mitigation elements in designs? If not, going beyond the prescribed minimum requirements (even where they exist) may be very difficult. Third, engineers themselves face financial, configuration, scheduling, and other limitations imposed on the design and construction process. Fourth, real or imagined potential liabilities associated with “going beyond” the governing prescribed minimum codes and standards can be a major barrier. Fifth, engineering organizations vary in size, wealth, level of interest, and other factors that can help or hinder the engineer acting as a “change agent.”

Overcoming Barriers. First, CBE must be seen routinely as a helpful tool that engineers can use to solve problems. Second, perhaps through existing professional engineering associations and organizations “CBE Users Groups” could be formed and supported by the MAE Center to address common knowledge and applications issues. Third, extending well beyond CBE and the MAE Center, there may be a need to change prevailing codes and standards. Fourth, efforts may be needed to change the perception that seismic requirements, CBE-based or not, do not add significantly to new project costs. Fifth, and perhaps most importantly, practicing engineers must recognize their roles as change agents and be trained to appreciate and perform that role.

### **Category 3. Institutionalizing CBE’s Adoption and Application**

#### **A. Technically Supporting CBE**

Consequence Based Engineering (CBE) relies on sophisticated data collection methods, analytical procedures, computer support (especially geographic information systems and visualization technologies: “MAEVIZ”), and intellectual resources to deliver the information it does. Few, if any, stakeholders will be able or desire to replicate this largely Federally-financed investment, but they will need applications support on a continuing and long-term basis. Alesch and Petak (2001) note that “Smaller organizations may need competent technical assistance, in the form of consultants or self-help instructional materials, to develop sufficient understanding to employ...risk reduction practices and to make prudent choices concerning risk reduction...(64) Only the MAE Center, and perhaps through some trained intermediaries (e.g., CERl, CUSEC, user groups) can provide this technical support.

Potential Barriers. First, financing software technical support services can be expensive. Second, which probably will be beyond the Center’s abilities, technical support will be needed on a timely basis. Third, depending on CBE’s evolutionary pace, the “software

upgrade syndrome” with its implied costs, additional learning, and other requirements could become a barrier to the method’s application.

Overcoming Barriers. First, the MAE Center should begin now to develop a “CBE Service Center” where users could seek help in applying CBE to specific decisions (i.e., “consulting”) and that defines likely user needs and creates means for addressing them in a timely way. Second, the Center should continue to invest in its already successful outreach activities, such as professional seminars, student development activities, and informational materials, but the materials and activities will have to address CBE concepts and applications in particular. Third, and also a continuation of its current activities, the Center could work with selected stakeholders to place recent graduates or interns in their organizations with the specific purpose of helping the stakeholders apply CBE and to act as a knowledge link to Center faculty and researchers.

## **B. Affecting Decision Agendas, Priorities, and Resources**

Everyone and all organizations, some more formally than others, establish agendas, set priorities, and allocate resources to further their goals. Agendas contain a limited number of items, some more important or more immediate than others, and competition for agenda space can be fierce. Moreover, agendas reflect influences about what gets considered at any given time (and what does not); thus “agenda management” becomes critical to decision-making. Reflecting on private organizations, Alesch and Petak (2001) conclude preliminarily that:

Private organizations are more likely to implement risk reduction practices when they see that the risk poses a clear and present danger to their enterprise. To the extent that natural hazard risk reduction can be coupled with routine business concerns, such as property and casualty insurance and risk related management concerns, it is more likely to come to the attention of the organizational decision makers. (62)

Typical reasons for not including items on agendas include “remoteness” of the problem (i.e., it is not a pressing issue), no or unsuccessful external or internal advocacy for an item’s inclusion, fuzziness of the information that makes the item unready for deliberation and decision (i.e., needs more exploration and refinement before presentation), lack of expert consensus on the need and scope of the decision (i.e., the problem is overstated and the solution is too expensive), and actual suppression (i.e., deliberately choosing to not deal with the issue).

Research in the natural hazards field has shown that only occasionally and for short periods does the subject appear on decision agendas, usually in association with some requirement (e.g., passage and compliance with a new law), a “trigger event” (e.g., a locally relevant damaging earthquake), presence of an influential advocate or advocacy coalition (e.g., seismic safety committee), or as part of some other decision (e.g., adoption of a capital improvement program that includes hazard mitigation standards or projects).

Potential Barriers. First, it can be difficult to access the very few people in key positions who control decision agendas. Second, lack of salience—or non-visibility of the issue—makes it difficult to get attention. Third, policymakers and decisionmakers “sit on their hands” when experts seen as equally competent have divergent opinions. Fourth, may be the lack of a requirement to address the earthquake risk issue.

Overcoming Barriers. First, learning from relevant earthquakes and applying that knowledge to a stakeholder’s particular situation is critical to achieving attention—and getting on the decision agenda. Second, recruiting respected internal or well-connected external champions can help get seismic safety on decision agendas. Third, prospective or actual laws or regulations that affect stakeholders’ interests almost assuredly will secure a place on decision agendas. Fourth, the occurrence of an unforeseeable event can force risk reduction onto the decision agenda.

### **C. Recruiting and Supporting Early Adopters**

CBE’s long-term acceptance and application will, at least initially, depend greatly on positive experiences by leader users: early adopters. Leadership and risk-taking (i.e., the willingness to innovate) play important roles in social change. It is true for earthquake risk reduction in general and for CBE in particular. The literature suggests that it takes a combination of things—knowledge, available technologies, advocates and champions, a supportive culture, resources, and courage—to innovate. Alesch and Petak (2001) propose that “Successful implementation of new policies and approaches is less likely to occur in organizations that traditionally resist change or have a culture that resists innovation,” but successful implementation will occur more promptly in organizations that are amenable to change. (45, 60)

Sometimes innovators emerge because of their interests and objectives, and at other times leaders have to be recruited and groomed for their roles. CBE, being a research-based analytical method, will have to depend greatly on users’ willingness to innovate to be successful. For example, Taylor, et al. in their study of lifeline organizations found that “the management organization structures evaluated are relatively flat, with inside technical advocates typically having direct access to top-level decision-makers.” (53)

Potential Barriers. First, it may be difficult to find one to three early adopters who would be receptive to establishing new or modifying their existing approaches in favor of CBE. Second, the Center may find it difficult to provide the level of support early adopters may need to apply CBE. Third, early adopters, regardless of their interest, may encounter difficult external barriers, such as using CBE data to upgrade existing buildings, when local codes, standards, and permitting procedures make it difficult to do such projects.

Overcoming Barriers. First, the MAE Center faculty and staff should work closely with a core group of stakeholders to foster the adoption of CBE methods and document the stakeholders’ applications of CBE, including its successes and difficulties. Second, MAE Center leadership should consider how the center will be able to provide services, including supportive actions, to help overcome external barriers. Third, all parties must

understand and be sensitive to the context (e.g., attitudes of local building officials) in which they will be applying the new methods.

#### **D. Identifying and Publicizing Demonstration Projects**

Successful real demonstration projects, such as San Bernardino County's construction of the first base isolated building in the United States, helps build consensus and legitimate a new approach, provides a learning experience for others who might consider adopting the innovation, and identifies advantages and challenges for subsequent users, making it easier for them to secure required approvals and to apply the methods to their projects.

Potential Barriers. First, and closely relating to recruiting and supporting early adopters, will be identifying potential projects that are sufficiently visible to serve as powerful symbols of change. Second, extra costs may (or may not) be associated with the demonstration project. Third, internal and external approval authorities may vary in their willingness to innovate.

Overcoming Barriers. First, the "best" demonstration projects are those where data is readily available and owners are willing to publicize and "showcase" the project. Second, a coalition of internal and external champions, with the proper credentials and decisionmaker support, may be needed to overcome inertia. Third, special attention needs to be given to including those responsible for controlling applications contexts (e.g., practicing engineers, building officials, legislators) throughout the process so each subsequent project is easier to do and regulatory systems are adapted to accommodate the innovation—which eventually becomes an accepted design method. Fourth, comparative cost methods (e.g., life-cycle, benefit-cost) may be needed to show cost advantages over traditional front-end design and construction costs.

### **Category 4. Considering Other Factors**

#### **A. Exploiting "Trigger Events"**

It is a truism that significant events, such as damaging earthquakes or even "credible" predictions, open the well documented "window of opportunity." CBE can bring potential loss and consequence information to the table where it, and other analytical methods, could provide a reasonable basis for reaching consensus on needs and priorities and then developing and advocating risk reduction measures.

The window usually is open for relatively short periods, and as time passes it becomes increasingly difficult to advance earthquake risk reduction proposals. The opportunities can be exploited, but it is difficult to do without some advance planning, organizational capabilities, and advocacy coalition building. In general, time is too short to mobilize and develop and advance an action agenda before the window starts to close and seismic safety loses its competitive advantage. Taylor and his colleagues found, for example, in their study that:

When a window of opportunity such as an earthquake presents itself, inside advocates possessed of technical earthquake knowledge take advantage of this window of opportunity to make a well-orchestrated presentation of earthquake programs to top-level management. Although having a short-term attention span for catastrophes, being easily diverted by more pressing matters, and having a fragmentary view of earthquake issues, the top-level managers nonetheless relent during this window of opportunity. So the seismic risk reduction program begins. Once begun, its inertia along with this initial top-level management endorsement permits its continuation. (52)

Potential Barriers. First, relevant trigger events may not happen very often. Second, even if an advocacy group can mobilize quickly, a willing “insider” leader or champion may be difficult to find. Third, and perhaps especially important to lower seismic regions, might be the “we have had our earthquake” attitude.

Overcoming Barriers. First, steps should be taken to develop and sustain organizational connections so the advocacy coalition can mobilize quickly. This may be done best through intermediary organizations, such as CUSEC, CERI, or emergency management agencies’ earthquake program officers. Second, MAE Center researchers and others should continue learning from earthquakes so applicable lessons can be learned and documented for potential application in the mid-America area. Third, communicating risk information must be continued.

## **B. Tackling the “Right Problem” Too Early**

Addition to the nation’s building stock averages about two percent annually. This relatively low turnover rate means that reducing earthquake risk in the short-term (as opposed to relying upon long-term attrition) depends on addressing the safety of the existing building stock. Sometimes labeled as a “stock and flow” problem, the challenge is to prevent new non-earthquake resistant buildings from flowing into the inventory while efforts are taken to correct the existing stock’s deficiencies.

Ensuring that new buildings contain earthquake resistive designs is far easier (comparatively) than dealing retroactively with the existing stock. Yet, loss estimates and experience show that certain well known classes of existing buildings are earthquake hazardous. This leads to an understandable desire to rehabilitate, retrofit, remove, or change the use of hazardous buildings—the “right problem.”

Experience and research shows how controversial and complex the existing buildings problem becomes when it surfaces as a seismic safety goal. While there may be a very small percentage increase in cost for adding earthquake resistance to new buildings during their design and construction, the direct costs and social impacts associated with modifying or replacing existing buildings can be very high, sufficiently so to mobilize powerful opposing interests (e.g., building owners, tenants, developers) that could jeopardize all seismic safety efforts. Avoiding the “too early” trap means that it might take decades to improve the existing building stock unless it is done voluntarily (rarely),



but initially focusing on less controversial and costly earthquake risk reduction measures will not endanger the entire effort.

Potential Barriers. First, the risk and dangers posed by existing buildings may be discounted by those who might be affected. Second, strong and vocal opposition from affected interests to proposed regulatory measures is “guaranteed.” Third, there will be controversy about methods, schedules, criteria, and the distribution of costs. Fourth, there are likely to be disagreements among “equally qualified” experts, which will lead to non-decisionmaking.

Overcoming Barriers. First, seismic safety advocates should acknowledge the complexity of the existing buildings problem but not address it prematurely. Second, voluntary and negotiated improvements to existing buildings, while not expected to be numerous, is progress and provides important examples. Third, “it can happen here” lessons from other damaging earthquakes should be documented and publicized with the intent of creating a “climate change” in attitudes toward the existing building stock.

### **C. Achieving Implementation via Incremental Rehabilitation**

Buildings and facilities need periodic repairs and modifications to continue to fulfill their needs. These provide opportunities to lessen risk by correcting safety deficiencies, but maybe not all at once. Evidence exists, including a Missouri school district, that incremental seismic safety improvements, such as properly connecting roof structures to load bearing walls during reroofing, can, with voter approval in this case, be included in ongoing facility maintenance programs. This helps to avoid the “earthquake only” reason and expense, especially in lower seismic regions.

Potential Barriers. First, getting seismic safety on the agenda of work to be done may be difficult. Second, some people may see a long-term incremental approach as inadequate, given their perception of the risk. Third, there may be a perceived or real liability issue associated with addressing only part of the problem when the full extent of it is known.

Overcoming Barriers. First, it will take knowledgeable leaders to get incremental seismic rehabilitation included in facility maintenance and modification plans. Second, even given a shared knowledge of the risk, doing something feasible with the resources available may be a preferred and more defensible strategy than doing nothing.

### **D. Disaster Assistance and Insurance**

There exists an inherent conflict between stakeholders investing in mitigation/loss prevention measures to reduce future losses and those who choose a risk management strategy that relies primarily on others paying when losses actually occur. When a stakeholder decides to transfer its financial responsibilities for recovery from itself to another party, that decision can remove the incentive to invest in loss prevention, such as strengthening an existing building, unless a third party requires loss prevention actions be taken as a condition of the work to be done or its possible future financial support.

Potential Barriers. First, is not appreciating the extent of potential direct and indirect losses stakeholders could experience, which can lead to underestimating the financial and operational impacts of earthquakes on their organizations. Second, stakeholders may not understand the eligibility requirements (which change frequently) and limited roles assistance programs play in loss compensation. Third, disaster recovery can take years, and loss compensation often does not come quickly.

Overcoming Barriers. First, vulnerable organizations should assess the full impacts of potentially damaging earthquakes on their assets and functions to help them evaluate the need for earthquake risk reduction measures. Third, even if much of their losses are compensated eventually, organizations could, if not required to do so, plan to replace or improve their facilities during recovery to help avoid future losses.

### **E. Using Non-Capital Intensive Risk Reduction Options**

CBE will provide potential loss and impact information to inform stakeholders. From an engineering perspective, recommended earthquake risk reduction measures often focus on expensive capital improvements, such as strengthening or replacing buildings, structures, and network elements and anchoring nonstructural elements. However, the nature of the organization itself—single location, multiple local locations, or widely (even globally) dispersed multiple sites—becomes important because stakeholders have other “soft” and lower cost options available to them: relying on redundancy and contingency planning, for example.

Redundancy includes having widely dispersed sites that perform identical functions and whose capabilities can be increased readily (e.g., by adding shifts and redirecting resources). Contingency planning includes procedures to relocate management and administrative functions, assure an effective on-site response, and implement recovery procedures to minimize business interruption.

Potential Barriers. First, there may little or no interest in any aspect of emergency management, especially if the threat is perceived as remote. Second, decisions tend to favor immediate problem-solving and mission or goal accomplishment, such as increasing competitiveness or maintaining profitability, rather than investing in negative wealth-creating (i.e., “overhead”) activities. Third, the lack of disaster or business interruption experience is a barrier. Fourth, tenant organizations may be prevented from improving their leased facilities.

Overcoming Barriers. First, capital improvement programs often guide organizations’ decisions about the future of their facilities and locations, and risk reduction factors can be added to the considerations included in such plans. Second, earthquake risk reduction measures can be combined with other organizational goals to achieve multiple objectives. Third, contingency plans, when they are linked with facility improvements, can greatly enhance organizations’ abilities to restore activities with minimal interruption by lessening expected damages and facilitating effective postdisaster recovery.

## **F. Time**

The evolution of the CBE methodology has taken nearly a decade of research. The MTB project, launched this year (2003), is the first test application of CBE in a particular geographic and stakeholder setting. It is clear from the literature that, absent some unusual major triggering event, the acceptance, adoption, and implementation of earthquake engineering innovations takes time. In his recent review of three earthquake engineering innovations, May (2002) concludes “that it takes at least two decades to move beyond the initial threshold of early applications and guidelines to widespread adoption of the innovation.” (36) Time itself moves inexorably forward, and many of the barriers discussed below relate generally to timing.

Potential Barriers. First, learning takes time under normal circumstances, and it may not be available, especially when it involves the understanding of and commitment to using new practices and methods. Second, adopters and implementers may not see benefits from using the new methods. Third, generational attitudes may affect the willingness to learn. Fourth, complex institutional, procedural, legal, and regulatory environments may need to be changed to support an innovation’s adoption and implementation.

Overcoming Barriers. The challenge is to overcome them “in due course” so the adoption and application of CBE will happen. Many of the means for overcoming barriers also discussed above, such as maintaining long-term technical support, providing professional education, continuing advocacy, supporting early adopters, using demonstration projects, and developing strong user relationships could help shorten the “knowledge-application” time gap.

## **CONCLUSION**

Although the barriers identified and discussed above do, in fact, seem “formidable and daunting,” not every one will be present in every circumstance, at the same time, or be equally influential. In his report on Performance Based Earthquake Engineering (PBEE), May’s (2002) reminder is that “implementation...will not occur, except in isolated cases, unless key barriers that are common to innovations in general and past earthquake engineering innovations in particular are overcome,” including:

Overcoming uncertainty about the methodology and its benefits...this requires clear and understandable explanation of the methodology accompanied by realistic applications of the methodology.

Addressing concerns about the costs of employing the methodology...An understanding of the costs of carrying out...analyses is clearly essential for overcoming this barrier—whether more costly or not—along with clear evidence of the added value (benefits) of the...methodology.

Addressing the complexity of the methodology and of required analysis procedures...[that] also requires clear and understandable explanation of the methodology, perhaps including simplified versions for some circumstances [such as] user friendly analytical routines.

Legitimizing the methodology...[by incorporating] the innovation into seismic guidelines and standards [which] was essential for acceptance...

Establishing comparative advantage...[by providing] at least as reliable and useable results as more traditional design and engineering methods.

Facilitating [the] early adoption...of an engineering innovation [by providing] special funding, technical assistance, or recognition for these efforts...[and] the use of evangelists to promote the benefits of new technologies. (33-35)

Alesch and Petak (2001) define several organizational prerequisites for the successful adoption and implementation of seismic risk reduction measures. These could provide a solid foundation for crafting CBE-based risk reduction measures in specific contexts and evaluating how the applicable barriers might be overcome or the opportunities seized.

The four “sequentially cumulative” prerequisites are: “the individual organization must perceive that it is at risk from the earthquake hazard;” “once the organization perceives itself at risk, it must also be convinced that an acceptable solution exists to reduce that risk;” “...the organization must conclude that implementing the risk reduction policies and practices is in its best interests at this time;” and “...it is necessary that the organization has the capacity and the ability to implement the risk reduction measures at this time.” (54-55)

Working Paper 3, *Strategies for the MAE Center*, recommends measures that could be taken by MAE Center leaders and researchers to influence and support the diffusion, acceptance, and application of CBE in a larger regional social context. However, the lesson is clear: as CBE moves from research into practice, the MAE Center’s chief roles will be to technically support CBE through additional research, demonstration projects, and participation in collaborative relationships with stakeholders who ultimately will be the adopters and implementers of improved earthquake loss reduction measures.

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# WORKING PAPER 3: RECOMMENDED CBE IMPLEMENTATION SUPPORT STRATEGIES

## Abstract

This brief paper, the concluding one of three, provides four recommendations for consideration by the Mid-America Earthquake Center's leadership as the Principal Investigator anticipates the movement of Consequence Based Engineering (CBE) from research and testing into practice (i.e., adoption and implementation) in a very diverse stakeholder/user community in a region subject to infrequent but potentially catastrophic earthquakes.

## INTRODUCTION

Consequence Based Engineering (CBE), the Mid-America Earthquake Center's intellectual and conceptual contribution to systems risk analysis, loss estimation, and mitigation intervention, will require the Center to play significant roles during at least the next ten years as CBE moves from research and testing into practice. This paper recommends strategies to assist the Center in fulfilling its knowledge transfer, technical advisory, and continuing research responsibilities to meet regional and perhaps national needs.

The following four recommendations, including corollaries for some, are based on the definition of CBE, which provided the foundation for this entire project. CBE is:

a new paradigm for seismic risk reduction across regions or systems that incorporates identification of uncertainty in all components of seismic risk modeling and quantifies the risk to societal systems and subsystems enabling policy-makers and decision-makers to ultimately develop risk reduction strategies and implement mitigation actions. (Abrams, et. al., March 2002, emphasis added)

CBE's holistic approach through MAEVIZ (CBE's automated visualization module) for characterizing earthquake risk and for demonstrating CBE's abilities to show the potential impacts of scenario events provides an all encompassing framework within which stakeholders of all kinds can assess their vulnerabilities, potential losses to their assets, and the direct and indirect impacts of the losses on clients and customers, service areas, network elements, and local and regional economies.

Working Papers 1 and 2, *Knowledge and Technology Transfer Models* and *Factors Affecting the Acceptance and Use of CBE*, respectively, plus interview data collected from selected Principal Investigators and representatives of intermediary organizations (i.e., those that could play key roles in technology transfer), the PI's experience, and applicable other studies and research helped shape these strategic Center-focused recommendations.

The Mid-America Earthquake Center, while its headquarters are at the University of Illinois at Urbana-Champaign (UIUC), is a consortium that includes other partners that collectively provide a multidisciplinary “critical mass” of expertise. The other partners are Georgia Institute of Technology, Washington University, University of Puerto Rico, Texas A&M (Agriculture and Mining), University of Memphis, St. Louis University, and the Massachusetts Institute of Technology. The Center’s critical mass designed CBE, and for CBE to be adopted and implemented in very diverse stakeholder contexts, the Center must remain as the methodology’s intellectual leader.

## **RECOMMENDATIONS**

### **RECOMMENDATION 1: The MAE Center should continue to be CBE’s intellectual and technical resource.**

- A. Translate and disseminate knowledge and lessons learned tailored to regional needs and applications. CBE will be applied in various contexts by potential stakeholders with vastly differing needs and resources. The fact that users need, and more readily use, information tailored to their situations or responsibilities means that elements of CBE will have to be “translated” from research terminology into “user friendly” language that can be applied over an extended period of time.
- B. Establish strong and continuing relationships with intermediary organizations to further the adoption and implementation of CBE. As CBE migrates from the laboratory to the user communities, the roles of intermediary organizations will become increasingly important. They serve as links between the “knowledge generators” (i.e., the consortium of universities composing the Center) and CBE’s potential users. The Center needs to build on its model relationship with the Center for Earthquake Research and Information (CERI) at the University of Memphis and expand it to other capable intermediary organizations. Some early possibilities include the regional chapters of the Earthquake Engineering Research Institute, the Central United States Earthquake Consortium (CUSEC), and local chapters of professional organizations. Later, this core group of earthquake-involved organizations could be expanded to other trade, professional, civic, industrial, and governmental associations that might be encouraged to add earthquake risk mitigation to their agendas.
- C. Continue providing education, outreach, training, and related professional human resources development activities. The Center has, through its outreach activities, developed an effective model and processes for reaching selected audiences and has strongly encouraged an interest in earthquakes among students—the next generations of practitioners and researchers. This foundation needs to be built on to reach a broader stakeholder base (see B above). The intermediary organizations can help provide the audiences and supporting informational materials, but the Center will be central to preparing and delivering information appropriate to users.

**RECOMMENDATION 2: Collaboratively with other organizations, the MAE Center should help stakeholders identify earthquake risk management problems, the solution of which will require research.**

- A. Develop partnerships with applications-oriented research and testing laboratories. As CBE moves toward implementation, and because stakeholders more often than not are applications and problem oriented, it could be important to work with applications-oriented and testing laboratories and their staffs to address problems within their domains. Two regionally important examples include the U.S. Army Corps of Engineers' Construction Engineering Research Laboratory (CERL) and the Construction Technology Laboratories (CTL).
- B. Lead the "CBE Stakeholder Network." Working Paper 2 describes the stakeholder community as being very pluralistic (resembling a "web") and agenda driven. CBE, being the Center's earthquake engineering innovation, means that the Center should provide the intellectual leadership needed to help the intermediary and stakeholder organizations develop sustained interest in CBE and its applications in largely problem-solving contexts. Should the Center not fulfill this role, interest in CBE will wane and its adoption and implementation will atrophy because, recalling May's 2002 statement, "it is a long way from the research laboratory to actual practice." (1)
- C. Design collaborative projects that support different reward systems so synergy results. It will be critical for CBE's long term acceptance and application that it be seen as helpful by problem-focused stakeholder and user organizations. It often is difficult to bridge the "researcher-practitioner" gap because of substantial differences in interests, obligations, needs, schedules, and rewards. Data collected for this project suggests that all participants can benefit from the relationship. For example, researchers need academically acceptable and publishable results, practitioners need solutions so their projects can move forward, and both desire peer recognition.

**RECOMMENDATION 3: Participate in advocacy efforts to influence risk reduction decisions and actions in or that affect the region.**

Knowledge is essential to designing effective measures to reduce earthquake risk, but knowledge alone is not sufficient. It must be an integral part of and support efforts to adopt and implement risk management strategies, standards, policies, laws, and other manifestations of seismic safety. Some advocacy efforts may be transitory, such as participating in public hearings regarding the adoption of building code changes, and others may be more durable, such as participating on seismic safety (or natural hazards) boards, committees, and commissions.

Regardless of the venue, when Center researchers bring their knowledge and experience to the advocacy environment, they become critical parts of broader advocacy coalitions



that can effect decisionmaking. One of the most important contributions researchers can make, beyond the activist role demanded of coalition members, is to convey the limitations of existing knowledge so proposed mitigation intervention measures are realistic and capable of being implemented.

**RECOMMENDATION 4: Lead the conceptual design of and the Center’s evolution into a regional multiple hazards research consortium by changing the composition and the number of member of academic institutions.**

While mid-America is exposed to occasional great earthquakes, their lack of frequency makes it difficult to effect change. However, other hazards, especially high winds and floods, are more frequent and, therefore, are a very salient public safety issue. The MAE Center could establish regular contact with other centers of expertise and their constituencies to define mutually supportive research agendas and relationships. For example, the various state flood plain managers could be of assistance if researchable issues of importance to them were to become part of the Center’s agenda, and Texas Tech University in Lubbock is the home of a Wind Science and Engineering Research Center. The newly emergent national “homeland security” agenda might also provide opportunities.

Academically based research centers are fragile organizations, however. While certainly understood by faculty researchers, others must be aware that researchers’ principal obligations are to their academic departments and their students. Centers depend on looser relationships where faculty members “lend their time” to work on matters of intellectual interest, particularly if financially supported from external sources, as is the case with the three earthquake engineering centers.

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