Implementation | 4

From earth science comes knowledge of earthquake hazards; from engineering, an understanding of how to prepare structures against them. For this knowledge and understanding to actually reduce earthquake losses, however, it must be put into effect. This process, the transformation of research results into real-world measures that will reduce loss of life and property, is referred to as *implementation*.

Implementation can take a number of forms. It can mean the incorporation of engineering lessons into the building practices of a seismically vulnerable region, land-use planning to restrict development of unusually dangerous ground, emergency planning to ensure service or business continuity in the aftermath of a major temblor, or informational outreach programs to inform potential earthquake victims of risks and preventive measures. It is a complex, multifaceted process involving many different players working at many different levels, and as such it is inherently challenging.

In many respects, implementation is the chief bottleneck hindering seismic mitigation efforts in the United States. Research in the earth sciences and engineering has already provided much of the knowledge base needed to prepare against earthquakes: we have a good idea of where earthquakes can occur (at least for the more seismically active areas); we have a sense of their potential severity and probable effects; and where we choose to prepare, we can significantly reduce the likelihood of massive destruction and loss of life. The problem is that we do not always choose to prepare. Despite mounting evidence that truly devastating earthquakes can occur in heavily populated regions of the central United States, Intermountain West, and U.S. East Coast, these regions remain highly vulnerable to future earthquake losses.

Moreover, where we do choose to act (most notably in the state of California), we have focused on issues of life safety and remain vulnerable to devastating economic loss.

These problems—a general lack of earthquake mitigation in many seismically hazardous regions (particularly outside California), and a surprising economic vulnerability in even the best-prepared communities—have drawn attention to how the implementation of seismic mitigation might best be improved.

The emphasis in the National Earthquake Hazards Reduction Program (NEHRP) has traditionally been on the front end of the implementation process (i.e., the gathering and dissemination of research knowledge and recommendations), with the actual execution largely left to state and local authorities, private organizations, and private individuals. As a result, implementation might be improved through better coordination and tailoring of front end efforts to the needs of nonfederal implementers. Alternatively, one might desire to complement existing efforts by having the federal government play a more active implementation role through incentives, insurance, or regulation. All such efforts require an understanding of how the implementation process works, who the chief players are, what their relations are to NEHRP and to each other, and what incentives or disincentives influence their desire or ability to act. Those seeking to improve mitigation efforts in the United States must therefore consider the following:

- How does implementation work in the ideal and in practice?
- What underlying factors reduce implementation success?
- What activities or measures have the greatest impact on implementation success?

These questions are considered in turn. The next section, “The Implementation Process,” examines the basic workings of implementation and identifies difficulties that arise in the execution of mitigation measures. Following that, “Factors Affecting Implementation” sets these difficulties in the context of larger motivational problems that complicate the widespread and thorough adoption of mitigation programs. Finally, the section “How Matters Might Be Improved” identifies earth science, engineering, and direct implementation measures that might improve mitigation adoption and execution.

THE IMPLEMENTATION PROCESS

The Voluntary Nature of Earthquake Mitigation

From the perspective of the federal government, the implementation of earthquake mitigation measures is an essentially voluntary process. Federally supported research gives warning of likely earthquake hazards while suggesting possible technical countermeasures, and concerned nonfederal entities decide whether to incorporate those suggestions into state, local, or private hazard reduction schemes.

The origins of this approach lie partly in the unusual scientific climate surrounding NEHRP’s conception (a point addressed later) and partly in matters of constitutional authority. That is, although federal funds can guide the course of research, the application of research results takes place primarily through land-use decisions and building codes—authority over which is constitutionally ceded to the states—and through action by individuals and nongovernmental organizations.

To explain in more detail, the essential goals of mitigation are to ensure that buildings and other structures do not collapse, that lifelines and services continue to function, that individuals and organizations are aware of risks and appropriate responses, and (a more recent concern) that economic losses are minimized. The basic tools to accomplish these goals are:

1. building codes for new construction in seismically hazardous areas;
2. retrofit or demolition programs and guidelines to reduce or remove the risk of potentially hazardous older construction;

3. land-use planning or zoning measures to prevent development on particularly dangerous ground (e.g., fault scarps and landslide zones), or to limit such development to nonessential, less vulnerable uses;
4. actions by individuals or nongovernmental groups to reduce nonstructural hazards (e.g., anchoring office equipment), or to initiate measures (land-use, retrofit, seismic-safety standards) beyond those recommended by the government;
5. structural, organizational, or emergency response measures to ensure lifeline survivability; and
6. the collection, processing, and dissemination of information on earthquake risk, mitigation alternatives, and earthquake response to at-risk individuals and organizations.

Of these tools, the first three (which have the greatest impact on reducing catastrophic building collapse and major loss of life) are building and land-use issues, while the fourth is, by definition, private. The federal government has some influence on lifeline survivability via authority over utilities and transportation (and of course on direct federal construction), but its basic role in implementation is currently focused on the last measure—collecting, processing, and disseminating information.[1] This handling of information serves two functions: one is to motivate nonfederal entities toward action by making clear both the risks and the potential losses; the other is to facilitate action by translating research results into readily usable forms (e.g., by incorporating engineering theories into ready-to-use model building codes).

Approaches to Implementation

With federal agencies currently playing a primarily informational role, authorities in the state, local, and private sectors are faced with devising their own plans for putting hazard reduction into effect. Because different parts of the country vary in their geology, hazard awareness, economics, political climate, and mitigation history, these plans show a wide range of approaches:

- The overall approach can be regulatory, incentive- or insurance-based, or built on outreach and the media.
- Action can be initiated by states, localities, professional and technical associations, or the private sector.
- In some instances (e.g., hospitals and schools in California), the state takes a direct role in mandating preventive measures. Alternatively, the state can issue voluntary guidelines for local jurisdictions, or it can set performance standards that local authorities must attain.
- Considerable discretion is commonly left to local governments. Where state activity is weak, local authorities sometimes take the lead (indeed, localities in even the most active states are free to adopt more stringent measures than required).
- Finally, important mitigation decisions can be made at a nongovernmental level by regional or local utilities, private businesses, professional societies such as those guiding the training and practice of engineers, organizations governing particularly sensitive institutions such as museums and laboratories, and private individuals.

Despite the variety of mitigation approaches, some common themes recur. In deciding whether and how to guard against earthquake hazards, communities, organizations, and individuals will generally seek to:

1. assess the local level of seismic hazard and local vulnerability to that hazard,
2. decide what changes should be made to the existing and future built environment while ensuring that the benefits of such changes outweigh the costs, and

[1] The federal role could be larger, and options for making it so are presented in chapter 1. However, this discussion reflects the federal role as it currently exists.

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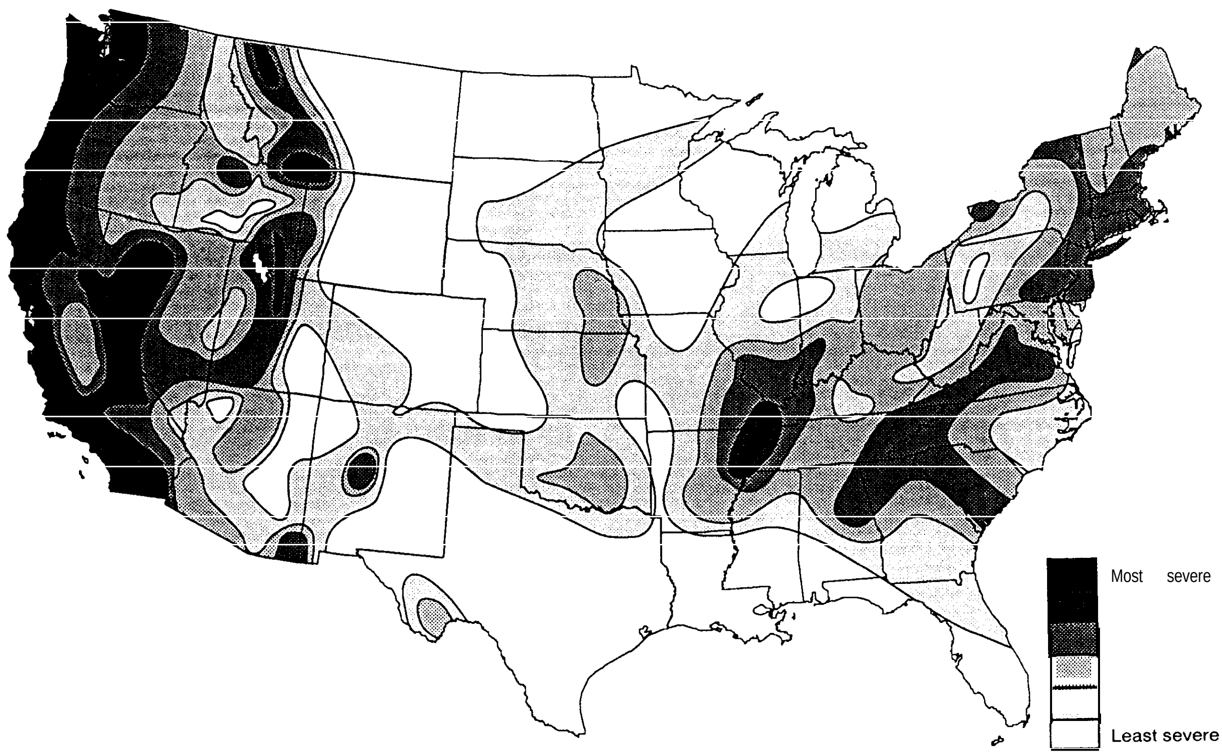


A community's first step in assessing earthquake risk is to consult large-scale seismic hazard maps; here, the severity of future ground shaking is shown for the continental U.S.

3. devise regulatory, financial, insurance-based, or cooperative tools to put those changes into effect.

Although simple in concept, these steps—particularly the first-are not straightforward to execute. To illustrate the difficulties that arise, the remainder of this section examines how a hypothetical (and unusually thorough) community might approach each of the above steps. For clarity's sake, each step is presented in sequence, with the assumption that conscious, rational thought governs every phase of the process. In the real world, communities or individuals will likely deal with steps simultaneously or in varying sequences, perhaps making decisions on the basis of less-than-formal deliberations; however, the basic problems that arise are the same whether the decisionmaking process is explicit or implicit.

■ Assessing Hazard, Risk, and Vulnerability

Assessing Overall Hazard—Seismic Hazard Maps

As a first step, this hypothetical community will examine U.S. Geological Survey (USGS) seismic hazard maps[2] to gain a sense of the overall danger. Of concern are:

- the frequency of seismic activity and the likelihood of activity within a future time window,
- the most likely severity of future events, and
- the severity of the worst-case event.

All three points are subject to considerable uncertainty, and all have an impact on the scope and character of the desired mitigation action.

The first point reflects the immediacy of the earthquake threat and can determine the choice of implementation tools. If a community can reason-

[2] There are many types of seismic hazard maps. See chapter 2 for more details.

ably expect a damaging quake several hundred years from now[3]—by which time most or all of its current building stock will have already been replaced—then seismic codes for new construction might suffice for future protection. However, if a major seismic event is expected within the next few years or decades (i.e., within the lifetime of many existing buildings), prudence may dictate more drastic measures such as building retrofit or demolition and replacement. The difficulty is that situations are rarely so straightforward. Because earthquake likelihood is commonly expressed as a probabilistic estimate (i.e., there is a percentage chance of an event during some future time interval) and because building lifetimes vary widely, communities must judge the impact of an uncertain future event on an evolving building stock. As a result, communities must balance the risk of overmitigation (e.g., by tearing down or retrofitting structures that would never have experienced an earthquake) against that of mitigating too slowly and being caught unprepared.

Apart from issues of urgency is the question of earthquake severity: should one prepare for the worst-case scenario, or for the most-likely? The geologic stresses that lead to seismic activity (see chapter 2) can be released by earthquakes of many different sizes, and those preparing for them must choose from a range of predicted calamities. This choice creates problems for those trying to justify the expense of mitigation, for over- and underpreparation can both waste money: overpreparation is expensive for obvious reasons, while an expensively but inadequately prepared building can still be destroyed at a a total loss.

Assessing Risk in Detail

It is tempting to stop the assessment process at the level of the seismic hazard map—knowing the predicted zone of devastation surrounding future earthquakes, one could in theory simply require that all structures within the zone be built to seismically resistant standards.

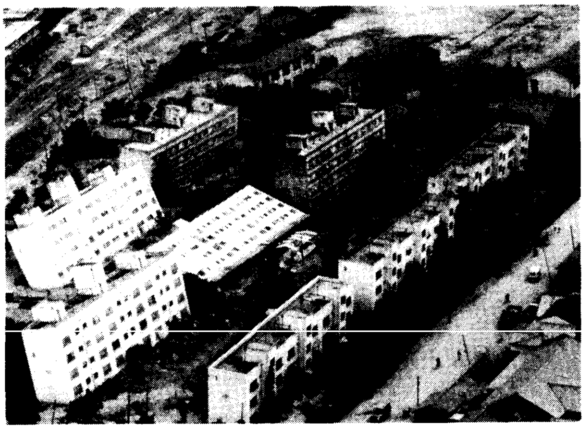
Real-world costs however make a broad-brush approach impracticable on two counts:

1. In many regions (particularly east of the Rockies) scientific uncertainties mean that enormous portions of the seismic map are marked as potentially hazardous. A broad-brush mitigation strategy can therefore prepare a widespread area for a future earthquake that, if and when it occurs, might strike but a small fraction of the region.[4]
2. Even if predicted earthquake locations are tightly constrained, a broad-mitigation strategy can still be undesirable. Within the general area affected by an earthquake, quirks of local geography and geology will make some localities much more dangerous than others (see chapter 2); these quirks are largely ignored in the preparation of seismic maps. Applying an average level of mitigation to the entire area will thus tend to overprepare some localities while underpreparing others.

For practical and economic reasons, a community will therefore wish to focus its efforts on locations where devastation is most likely. Places subject to ground failure, seismic energy amplification, and other earthquake-related effects (see chapter 2) can experience the bulk of a region's earthquake damage and will call for special attention (or sole attention, if the commitment to mitigation is weak). Because the typical seismic

[3] Such an expectation can never be certain, for there is a certain probability that an earthquake can occur at any time; however, a community in a seismically inactive region may judge its near-term earthquake risk to be too low to warrant drastic action.

[4] This form of overpreparation is particularly troublesome where earthquakes are infrequent, in which case many of the region's buildings will never experience an earthquake during their lifespans.



Earthquake-reduced ground failure (liquefaction) can endanger even the most well-constructed buildings (Niigata, Japan, 1964).

hazard map predicts only the average severity of ground shaking that would occur on an average piece of land, the community will likely have to conduct its own study of local geologic conditions. This sort of "microzonation" assessment is typically far beyond the technical capability of a local government, and although some metropolitan regions have been studied through state efforts or because of special interest on the part of earth scientists, a community will generally have to hire a geotechnical firm to perform the work.

Assessing Vulnerability: Inventory and Damage Estimation

Although one might expect the damage pattern in a community to coincide with the pattern of maximum ground shaking (subject to the microzonation effects noted above), the damage a given building experiences in an earthquake will depend on its design, the type and quality of its construction, and how the building reacts to the particular ground motion characteristics of the earthquake (see chapter 3). Hence, it is not enough to know the local geology and geophysics-one must also estimate how the building stock will respond. Such an estimate requires an accurate inventory of the local building stock and predictive tools relating earthquake damage to building type.

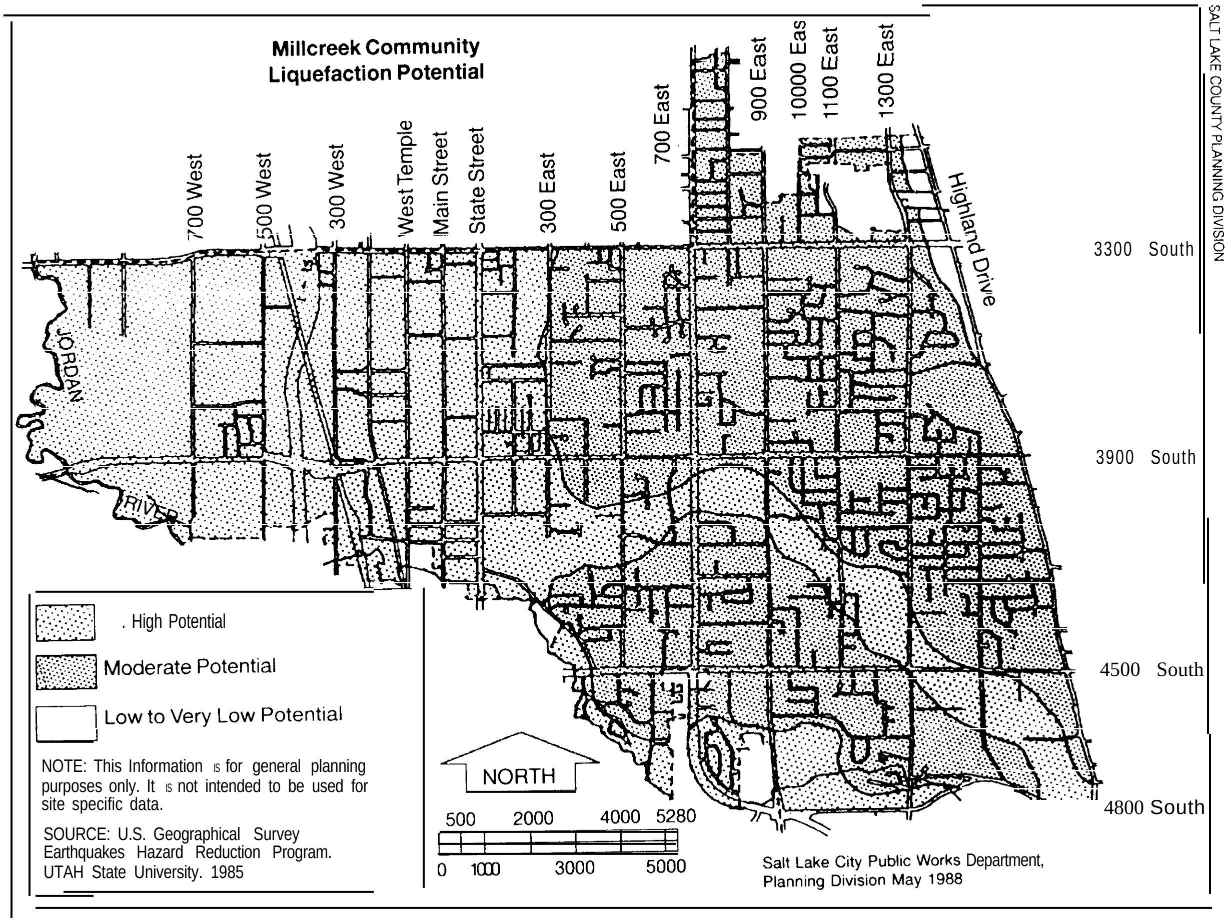
Unfortunately, most communities do not possess workable building inventories. Inventories may simply not exist, they may be outdated, or they may be expressed in terms that are of little use for mitigation (e.g., an inventory developed for tax or urban planning purposes might classify buildings according to function while including nothing about their construction).

A concerned community will therefore probably conduct a building survey to learn what buildings it has, what condition they are in, and where vulnerable structures are located. Again, this is not a straightforward task, particularly when it comes to the most worrisome older structures. That is, it is generally not enough to simply walk down a street and note down what buildings stand along it: a given "old building" might be made of unreinforced masonry; reinforced masonry; or some hybrid, much modified arrangement of wood, stone, metal, or concrete. Therefore, a judgment on its construction and vulnerability may require physical inspection by a specialist.[5]

Finally, having determined its building inventory, the community must relate that inventory to what it knows of the earthquake hazard and come up with an estimate for likely future losses. Ideally, this estimate will include economic loss and casualty figures broken down by building type and geography. Again, such an estimate is not straightforward, because the relation between earthquake damage and building design or construction is as yet poorly understood. However, if it can be done, such an estimate will allow a community to target those areas in which it is most vulnerable, and expend less of its resources in areas that are more robust.

Earthquake loss estimates thus function as a mitigation tool of singular importance. By reducing mitigation costs while increasing the likely

[5] The technical expertise requied for such an inventory suggests a possible avenue for federal implementation assistance.



Detailed risk assessment requires the preparation of small-scale seismic zonation maps, in which local geologic dangers are matched to features of the built environment. Here, the potential for liquefaction in a Utah community is over/am on a map 01 city streets.

benefits, a quantitative loss estimate can increase the effectiveness of current mitigation efforts while making it much more likely for as yet undecided communities to act. Unfortunately, although work is progressing on this front, reliable, consistent estimates are extremely difficult to obtain.[6]

The Office of Technology Assessment (OTA) notes an exceptional lack of quantitative information on expected earthquake losses in specific urban areas of the United States. Loss estimates have been made for certain regions (most notably, metropolitan areas in California), but variations in methodology, scope, assumptions, and even terminology make interpreting or comparing their results difficult. Further lacking are comprehensive data showing the change in expected losses that would result from mitigation--data essential to judging the cost-effectiveness of different mitigation measures. Indeed, many at-risk communities (particularly smaller urban centers in areas outside of California) have little more than a sense

[6]The Federal Emergency Management Agency, under NEHRP, is sponsoring the development of a computer-based loss estimation tool that could allow communities to estimate risk and prioritize risk reduction efforts.

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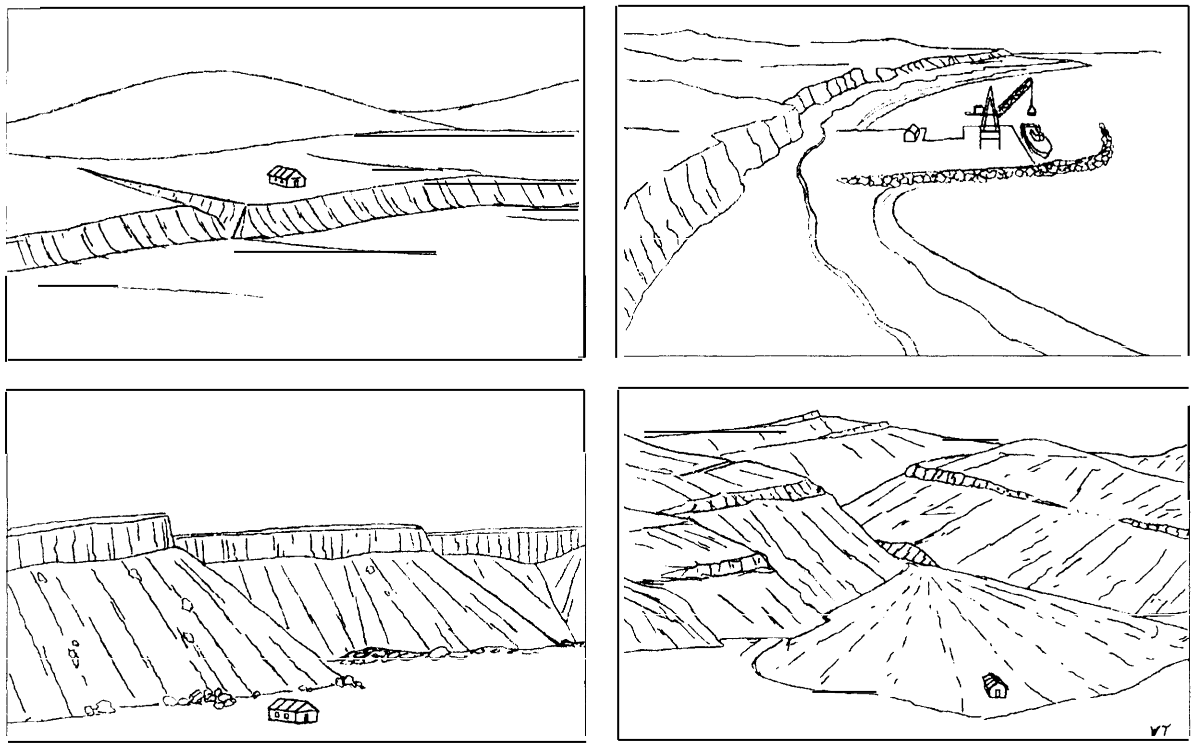

Land-use planning measures are best employed where local geologic conditions create unusually severe hazards (e.g., clockwise from upper left: fault scarps; landfills and land reclaimed from the sea; outwash and alluvial fans; unstable slopes).

that some sort of disaster might happen sometime in the future, and that some sort of preventive action should be taken. Missing are hard data on what are the expected losses, and in what functional and geographic areas will they occur. Without such data, communities can only guess how to respond.

■ Modifying the Built Environment

Having assessed the risk as well as it can, a community has a choice of mitigation tools with which to proceed. Possibilities include:

- land-use planning and zoning,
- building codes for new construction,
- retrofit or demolition of older construction, and
- systems-related, small-scale, and private activity (including emergency planning).

Although each of these has an impact on both life safety and economic loss, the first three tend to affect life safety issues, while the fourth is more directed toward economic damage.

Land-Use Planning and Zoning

The simplest and most drastic mitigation option is to avoid building things where earthquake hazards are expected. However, such an option is also the least used, and in practice land-use planning generally entails not the outright banning of development, but the tailoring of land use to forms less susceptible to earthquake damage.

Abolishing development on hazardous ground is most acceptable when the risk is clear, the alternatives are poor, and the geographical extent of the expected damage is limited. For earthquakes, circumstances meeting these criteria are relatively rare. The presence of a historically active surface fault rupture offers a possible candidate, in that the likelihood of future fault movement is evident, the engineering options are nonexistent (few structures can resist being torn in two, regardless of their construction), and the most damaging geologic effects occur in a tightly constrained area immediately adjacent to the fault.

However, even where conditions seem right, strict land-use measures such as development bans rarely appear as a mitigation tool. The history of earthquake disasters shows no end of instances where major structures have been built along known faults, even in seismically aware California (e.g., the stadium of the University of California at Berkeley sits atop the Hayward Fault), and with relatively rare exceptions (e.g., the "Faultline Park" in Salt Lake City), such measures are generally unpopular.

The roots of this unpopularity lie in the geographic nature of the earthquake phenomenon. Unlike floods, which typically strike clearly defined parts of floodplains and coasts, the primary earthquake hazard—ground shaking---can be distributed over an area so broad that general development bans become impractical (clearly one cannot halt construction in all of Los Angeles). Even local bans in places of obvious fault rupture or ground failure are often thwarted by a variety of socioeconomic objections (e.g., earthquake faults possess a perverse ability to create potentially valuable real estate with spectacular views). Moreover, typical seismic recurrence intervals of a lifetime or longer mean that bans must be maintained through years or decades of seismic inactivity.

The more likely use of land-use planning is thus in a milder form in which development on dangerous land, though permitted, is restricted to its less vulnerable forms. Thus, for example, a community might identify an undeveloped parcel of land that is subject to liquefaction or landslide, and limit construction to single-story, low-occupancy dwellings, or perhaps to noncritical industrial uses such as warehousing (such is one effect of California's Alquist-Priolo Act, see box 4-1). In this way, land-use planning is used not to prevent earthquake damage outright, but to reduce its direct and indirect impacts. Alternatively, a community might designate high-risk areas as sites

PHILIP R. BERKE

Areas of extreme earthquake hazard-such as this fault scarp in Utah—are often attractive locations for development.

requiring special geologic and engineering consideration before building can proceed (as in Utah's Salt Lake County Natural Hazards Ordinance, see box 4-2), thereby ensuring that vulnerably sited structures are more seismically resistant than the norm.

Building Codes for New Construction

With land-use planning reserved for special cases, a concerned community will commonly turn to the most broad-based of mitigation tools—the incorporation of seismic provisions in building codes. By using codes to effect seismically resistant construction, a community can replace the bulk of its building stock over time with one less vulnerable to damage and collapse. Because the approach does not restrict or modify land-use patterns, and because it is relatively inexpensive when applied strictly to new construction (see chapter 3), it can be more politically palatable than a broad-based land-use planning approach.[7] For all these reasons, building codes are perhaps the most popular of implementation options, and are often (erroneously) thought of as the sole tool of mitigation.

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[7] In some situations, land-use planning measures can be more politically acceptable than are broad-based building codes (as is the case in Salt Lake County, Utah.). However, such measures are adopted because they are *extremely* limited in geographic scope, and thus affect a relatively small number of buildings and structures.

BOX 4-1: Land-Use Planning in California: The Alquist-Priolo Act

The classic use of land-use planning to combat seismic hazards is California's Alquist-Priolo Act of 1972, This ordinance, which applies to the local government permit process for new construction, seeks to prevent structures from being built atop active earthquake faults. Its origins lie in the historical prevalence of active fault rupture (see chapter 2) in major California earthquakes, and reflects a belief that buildings and structures cannot be engineered to be resistant to fault motion. In concept, the act represents land-use planning in its purest form, and practical details of the act therefore illustrate basic problems in implementation.

The basic form of the Alquist-Priolo is as follows: the State of California, through its Division of Mines and Geology, identifies active faultlines and defines the land on and immediately adjacent to the faultlines as "Special Study Zones. " These zones are typically 600 feet to a quarter mile wide, with the width reflecting the degree of uncertainty over fault location and the amount of secondary fracturing of the ground on either side of the main fault. Those wishing to build within a study zone must submit a licensed geologist's report detailing the existence of active faults near the building site. If an active fault is found, buildings must be '(set back" from the fault (the amount of setback ranging from 10 to 50 feet, depending on the nature of the fault). In this manner, buildings are not sited where they are not expected to survive.

Though the Alquist-Priolo is straightforward in concept, practical matters of execution somewhat weaken its impact. The philosophical justification for the act is the government's responsibility to safeguard human life, and the legislation is therefore targeted at occupied structures. Structures occupied less than 2,000 person-hours per year are therefore exempt—an exemption that leaves out most lifeline system components (also exempt are single-family dwellings of wood frame construction, which though not resistant to fault motion, are less likely than other building types to fail in a lethal fashion). In addition, local expertise in geologic matters is required for successful implementation, as direct review authority over the required geologic reports is left to local governments.

Finally, the Alquist-Priolo contains a purely informational component, whereby a buyer of property that lies in a Special Study Zone is supposed to be informed of that fact. This provision of the act has been found to be largely ineffective in influencing buyer behavior.

SOURCE: Robert Reitherman, "The Effectiveness of Fault Zone Regulations in California, " *Earthquake Spectra,* vol 8, No 1 (Oakland, CA Earthquake Engineering Research Institute, 1992), pp. 57-78

Seismic codes, however, are not a panacea. In practice, their use involves a number of decisions and tradeoffs that can collectively reduce their impact:

- Seismic building codes do not govern every aspect of a community's building stock, but typically focus on specific parts of specific building types (thus ignoring certain aspects of building damage and economic loss).
- Codes cannot serve as a substitute for seismic engineering expertise, and indeed require skill and judgment on the part of their executors.
- Elements of the code adoption process (the steps that translate a seismic engineering recommendation into a specific code at the local level) often reduce code performance from the engineering ideal.
- Effective local enforcement of the code is crucial for reducing risk.

These points are discussed in turn.

Code coverage and philosophy

Although in theory codes can be written so that all buildings in a community are completely built to seismically resistant standards, in practice their application is more selective. Because the application of building codes involves a cost in money and effort, prioritization is necessary, and not all buildings and not all parts of buildings are treated equally.

BOX 4-2: Land-Use Planning in Utah: The Salt Lake County Natural Hazards Ordinance

A region subject to infrequent but potentially sizable earthquakes, the Salt Lake County of northern Utah (an area containing metropolitan Salt Lake City and some 40 percent of Utah's total population) uses land-use planning measures to reduce the impact of future damaging earthquakes. The intent of these measures is not to safeguard the general population, but to reduce the vulnerability of the built environment in unusually hazardous areas. This approach in part reflects the historical lack of seismic activity in the region and the consequent low public awareness of earthquakes and earthquake hazards: while broad-based mitigation measures such as new-construction building codes have engendered active regional opposition (because of feared mitigation costs), geographically limited land-use decisions—which are typically made by a small number of governmental and professional individuals—are less visible to the general public and hence inspire less controversy.

The centerpiece of the county's mitigation strategy is the Salt Lake County Natural Hazards Ordinance of 1989. Significantly, this ordinance does not treat earthquakes in isolation. Instead, seismic concerns are tied in with other natural hazards such as flood, landslide, and avalanche. This tactic allows the less common hazards--of which earthquakes are perhaps the rarest—to be handled by the same procedures that govern the most common, a move that further reduces opposition to the measure while minimizing additional implementation cost.

In outline, the ordinance works as follows: geologic and microzonation studies (some funded through the National Earthquake Hazards Reduction program (NEHRP) and the U.S. Geological Survey) are used to identify particularly dangerous "hazard zones. " Those seeking to develop sites within those zones can be required to prepare a special engineering geology study delineating ***all*** of the local natural hazards and explaining how the hazards will be dealt with (the nature of the hazard zone and the Intended use of the site dictate whether a study is called for). The study must then be reviewed by the county geologist, the Utah Geological Mineral Survey, and the Forest Service (in cases of avalanche threat), following which final approval must be obtained by the county's planning commissions.

The hallmark of this ordinance is extreme flexibility-a flexibility cited by county planning staff as crucial to the measure's success. With one exception (no buildings can be placed astride an active fault), the ordinance does not require any specific mitigation action. Developers are therefore free to develop their own mitigation tactics, be it through land-use measures like fault setbacks or through some engineering response. This flexibility is another factor favoring public acceptance of the ordinance, and is felt appropriate to the region's often complicated geology.

In turn, a flexible ordinance requires scientific and technical expertise on the part of county officials tasked with reviewing the engineering geology studies (and further demands that reviewers actively use their authority to halt unsatisfactory projects). Earlier incarnations of the ordinance were felt to suffer in effectiveness because this expertise was lacking. In this light, a critical contribution was made to regional mitigation efforts through NEHRP funding of a County Geologist Program from 1985 to 1988 This program, which placed a geologist on the staff of the Salt Lake County Planning Department to improve the geologic review process, was deemed so successful that the county chose to maintain the position following the expiration of federal funding.

SOURCES: Philip R. Berke and Timothy Beatley, *Planning for Earthquakes: Risks, Politics, and Policy (Baltimore,* MD The Johns Hopkins Universty Press, 1992), pp 40-62; and Carlyn E. Orians and Patricia A. Bolton, *Earthquake Mitigation Programs in Ca//forn/a, Utah, and Washington* (Columbus, OH: Battelle Human Affairs Research Centers, 1992), pp. 59-60, 69-70

SAN FRANCISCO CHRONICLE

Nonstructural damage-which most building codes do not address-can be considerable.

First and foremost, the seismic portion of a building code typically deals only with the building's so-called structural components (i.e., the frames, columns, beams, and load-bearing walls whose failure can lead to building collapse and consequent loss of life). Moreover, the structural components are not necessarily intended to survive a strong earthquake unscathed: if the component is damaged but does not collapse, the code is considered to have done its job. In other words, a code-complying building can "survive" an earthquake (i.e., not collapse and kill people) and still end up a shambles inside and out. This structural emphasis is in part philosophical, since the original intent of seismic codes is to safeguard human life. However, it also reflects a realization that greater levels of building protection entail greater construction costs.

Besides making a distinction between structural and nonstructural components, building codes distinguish in terms of building use. In general, structures that serve critical functions (e.g., hospitals) or house large numbers of people (e.g., schools) are held to a higher standard than are less important, more thinly occupied buildings. These distinctions again reflect the life safety focus of most codes and the great cost of more broad-based mitigation.

Because current codes are thus directed toward life safety, they have only an indirect impact on reducing economic loss. For one thing, the function or occupancy of a damaged building has little direct bearing on its cost of repair or replacement, and a focus on high-occupancy or critical facilities can leave vulnerable many less critical but costly structures. In addition, nonstructural building components such as stairwells, interior walls, ceilings, plumbing, and fixtures can be both dangerous and expensive in their own right (see table 4-l).

Concerns over earthquake-induced economic losses have led some to propose that the focus of seismic building codes be broadened to encompass more than issues of strict life safety. Overall damage reduction could then be pursued through the targeting of nonstructural as well as structural building components, or through the specification of minimum levels of post-earthquake building "functionality." In principle, such changes could be accomplished—although at some additional cost. As noted in chapter 3, however, the knowledge base for this is not yet well developed, and there is the chance that increased code complexity will cause its own problems (e.g., by perhaps aggravating already formidable problems in code enforcement).

Codes: no substitute for knowledge of seismic engineering design

Although a great deal has been learned in recent years about the design and construction of earthquake-resistant structures, most buildings are in fact designed by local architects and engineers far removed from the cutting edge of research. Some way must therefore be found to transfer knowledge and experience from the researcher to the practicing designer.

When resources are abundant, the knowledge transfer process can be direct. If the expense is warranted, one can require that a proposed structure be subjected to rigorous seismic engineering analysis by specialists in seismic design—that is, knowledgeable individuals with a professional obligation to stay abreast of developments in their field. Such an approach has the advantage of directly exposing the design process to individuals

TABLE 4-1: Nonstructural Building Elements Typically Unregulated by Seismic Codes

Exterior elements	Cladding, veneers, glazing, infill walls, canopies, parapets, cornices, appendages, ornamentation, roofing, louvers, doors, signs, detached planters.
Interior elements	Partitions, cellings, stairways, storage racks, shelves, doors, glass, furnishings (file cabinets, bookcases, display cases, desks, lockers), artwork.
Mechanical, electrical, and plumbing elements	Heating, ventilation, air conditioning equipment, elevators, escalators, piping, ducts, electric panel boards, life-support systems, fire protection systems, telephone and communication systems, motors, emergency generators, tanks, pumps, boilers, light fixtures.
Contents	Electronic equipment, data-processing facilities, medical supplies, blood bank inventories, hazardous and toxic materials, museum and art gallery displays, office equipment.

SOURCE: H.J. Lagorio, *Architectural and Nonstructural Aspects of Earthquake Engineering* (Berkeley, CA University of California at Berkeley, Continuing Education in Engineering, Extension Division, July 1987)

well versed in seismic principles, and is one often applied to major structures such as skyscrapers or nuclear powerplants.

The drawback of the engineering analysis approach is, of course, cost. Cost considerations are such that most buildings in the United States are constructed without the direct input of a seismic engineering specialist, and many of the smaller, more mundane structures (e.g., single-family dwellings) are "unengineered'' -that is, designed without any formal engineering input. For such buildings, seismic knowledge transfer can be accomplished through a code. Larger structures are governed by code guidelines that lead nonseismic engineers and architects through the design process; for smaller buildings, the codes offer specific, written requirements for how structures should be built. Such codes, which attempt to incorporate seismic design principles into buildings too small or inexpensive to warrant the involvement of a licensed structural engineer, in theory would require no specialized seismic engineering knowledge. That is, a competent builder or architect unversed in seismic engineering should, by following the code, be able to produce a structure that will not fall down in an earthquake.

In practice, however, the application of codes by competent but seismically unversed individuals will not always be successful. The reason for this failure is the need for flexibility within a building code. That is, although it is possible to write a "cookbook" code that unambiguously spells out exactly how a building should be built, such a code would be unworkable because:

- Successful results are most likely when the overall design of the building is of a type anticipated by the code writer—if the building is innovative or somehow out of the ordinary, the code may simply not apply.
- More fundamental] y, a cookbook code does not allow architects and engineers the flexibility to overcome the many unique obstacles that arise in designing buildings and structures.

Because of these concerns, building codes are written so as to give latitude for interpretation while providing some guidance for the inexperienced. Thus it is possible for the seismically inexperienced to rigorously follow a code, cookbook fashion, but still arrive at a vulnerable design.

In short, real-world variety in building design and construction requires that building codes be flexible, and this flexibility in turn requires that judgement be exercised in code execution. Thus building codes can work as intended only when working designers and building officials pos-

sess an adequate understanding of seismic design and engineering.

Code adoption process

The preceding discussion presupposes that seismic building codes are actually used in the design and construction of new buildings. How well a code works, however, is of little import if the code is never used. Local and state jurisdictions have considerable discretion over the content of their building codes, and many at-risk areas of the country have chosen to incorporate seismic codes only in part or not at all. The politics and economics of code adoption can thus have a greater impact on seismic safety than do technical issues of code performance.

The process of code adoption is as follows:

- The fruits of research sponsored by NEHRP and other organizations are distilled into a collection of reference documents, most notably:[8]
  1. *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*, Federal Emergency Management Agency (informally referred to as the NEHRP Recommended Provisions);
  2. *Minimum Design Loads for Buildings and Other Structures, ASCE-7-93*, American National Standards Institute; and
  3. *Recommended Lateral Force Requirements and Tentative Commentary, Blue Book*, Structural Engineers Association of California.
- These documents, which give suggestions for the stress or force levels that a building must withstand, along with "detailing requirements" that specify the design and construction of critical joints and structural elements, are not building codes. They are instead recommendations that may be incorporated by regional code organizations into idealized "model codes," the most well-known of which is the Uniform Building Code (UBC) of the International Committee Conference of Building Officials, which is used by much of the western United States. (Other model codes include the Southern Building Code Congress International used by southeastern states, and the Building Officials and Code Administrators code used in the northeast United States.)
- Although a model code such as the UBC is in fact a real building code, it does not directly govern the construction of any buildings. Instead, state or local authorities may choose to incorporate it wholly or partly into the codes actually used within their jurisdictions.

There are thus a number of hurdles to be overcome between the creation of a seismic code provision and its implementation. At the highest level, that of the recommended provisions, considerable effort is made to maximize the provision's cost-effectiveness and political acceptability. A successful effort will enhance the provision's acceptability and hence its chances for eventual adoption, but the necessary changes have the effect of making codes minimal, rather than optimal, requirements. At the intermediate level, model code organizations may pick and choose among the recommended provisions in order to meet their members' economic and political concerns. At the end-use level, states and localities will apply their own criteria as well in adopting the model code. **The result can be a wide gap between a NEHRP provision and an actual state or local code**.

Code enforcement: a continuing problem

Finally, the existence of a local building code does little good if it is ignored when the building is designed, and code compliance in a building plan is similarly irrelevant if the actual construction of the building bears little relation to the design. These failings do not imply dishonesty or malicious intent. Simple calculation errors at the de-

[8] Henry J. Lagorio, *Earthquakes: An Architect's Guide to Nonstructural Seismic Hazards* (New York, NY: John Wiley & Sons, Inc., 1990), p. 246.

sign stage, for example, can result in a weakened building, and construction elements such as plywood shear walls can be rendered useless by sloppy nailing. To guard against these and other failings, **a community concerned with seismic safety must invest resources into code enforcement.**

Building code performance therefore requires that plans and the actual construction process be checked by competent inspectors. Unfortunately, few data exist on the performance of local plan- or code-checkers, but anecdotal evidence from California's Northridge earthquake and from Florida's Hurricane Andrew suggest that problems of code execution and compliance result in significant economic losses.[9] The problem is poorly documented but broadly recognized, and represents an area in which improved performance can have benefits beyond simple seismic safety (e.g., improved code enforcement has the potential to lessen losses from wind and fire as well).

In summary, building codes for new construction, although relatively popular and potentially powerful, are no silver bullet: they generally cover only structural collapse, they still require some level of seismic engineering knowledge in order to work well, they might not reflect the latest thinking as captured in model codes or NEHRP provisions, and they must be enforced.

Retrofit or Demolition of Existing Structures

Despite the problems that can beset code implementation, building codes for new construction remain a powerful tool for improving the safety of the built environment. However, when a community has a substantial older urban core and the risk of an earthquake is immediate, the codes may work too gradually. Since the average new building will typically stand for 50 to 100 years before replacement, a community can expect about 1 to 2 percent of its building stock to be replaced each year (more, if the community is expanding and flourishing; less, if it is economically stagnant). Thus if a damaging earthquake strikes within a few decades of a code's adoption, large parts of the building stock will be caught unprepared. A concerned community might therefore consider the most unpopular and contentious of mitigation measures—retrofitting or demolishing vulnerable existing structures (i.e., older structures that do not comply with the latest version of the code).

The unpopularity of this option is manifold. One problem is cost: unlike the case of new construction, in which code compliance adds some 1 to 2 percent to the total building cost, a retrofit/demolition plan can entail enormous expense. Retrofitting an unreinforced masonry building, for example, will generally cost one-quarter the price of a new building (and can in some cases cost much more),[10] while demolition and replacement will of course cost full building value. Such expenditures understandably instill resistance on the part of building owners or anyone else who must bear the expense. In addition, the money spent is not necessarily recouped in the event of an earthquake: retrofits are primarily intended to prevent building collapse, and in some instances a retrofitted building can be just as vulnerable to expensive nonstructural and contents damage as an unmodified structure.

In addition to economic issues, there are considerable objections based on quality-of-life and demographic concerns. Unreinforced masonry buildings, potentially the most dangerous existing buildings, are structures that form much of the urban core of many U.S. cities. They are often prized for two very different reasons: 1) they can embody much of the architectural heritage and character of a city, and 2) they tend to provide most of the low-cost housing used by lower income groups. Demolition is therefore unpopular from both an

[9] Although current life safety-oriented codes cannot eliminate economic losses, they do—by preserving the structural integrity of buildings—have an often significant impact on direct economic losses.

[10] See chapter 3, "Damage to Buildings," for references and assumptions.

architectural and a housing point of view, while retrofits can lead to rent increases that drive away the original residents. For these reasons alone, city planners may hesitate to take such action, particularly where (as in the central United States) there is great uncertainty about the timing of future earthquakes.

Private, Small-Scale, and Systems Preparation

The three mitigation tools discussed above—land-use planning and zoning, new construction building codes, and retrofit and demolition programs—primarily affect the structural integrity of the built environment. If the primary concern is to reduce loss of life, these tools may suffice. However, they are not enough to curtail major economic losses in the event of a damaging earthquake.

Recent experience (e.g., the 1989 Loma Prieta and the 1994 Northridge quakes) has shown that structural collapses, although spectacular and newsworthy, are by no means the only source of earthquake-related losses. Economic losses also stem from business interruptions; loss of records and computer databases in the service economy; disruption of roadways, utilities, and other lifelines; and widespread, noncatastrophic damage to residential and commercial structures throughout the earthquake region. Although it is difficult to quantify the effect of these losses (particularly in the case of indirect economic damage), their significance is suggested by one estimate of direct residential losses in future earthquakes. This estimate implies that catastrophic building failure, which is what codes and retrofits are designed to prevent, will be responsible for less than one-tenth of California's future bill for direct earthquake losses.[11] Even neglecting the potentially significant issue of indirect losses (i.e., those pertaining to the disruption of business and services), we thus find that traditional mitigation tools of land-use planning, retrofits, and building codes can be largely undirected at reducing the economic impact of a major earthquake.

To mitigate against economic damage, a community must therefore encourage a varied assortment of measures that are collectively referred to in this report as "private, small-scale, and systems preparations." These are measures adopted primarily by individuals, corporations, and utilities to reduce the economic losses caused by various nonstructural failures. The distinction between these measures and structural tools is somewhat arbitrary (e.g., structural building codes can help reduce nonstructural damage, and lifeline-related losses ultimately stem from the failure of bridges, dams, and other structures). However, as a group the measures are ones requiring motivation, careful thought, and tailoring of strategy by individual end users, and as such are not well suited to broad-brush, mandated approaches.

Examples of such measures are:

- Encouraging individual developers and building owners to adopt design and construction techniques that exceed code requirements. As noted earlier, codes serve as a minimum standard, and future structural and nonstructural damage might be averted if a structure is built to a higher level of performance.
- Developing, *before* a damaging earthquake, contingency plans for rerouting traffic, dispatching emergency crews, establishing alternative water, power, and supply sources, and otherwise taking action to reduce post-earthquake indirect losses. Such activity, which requires considerable time, expertise, and coordination, can be taken by both governmental and private entities.
- Motivating individuals, businesses, and organizations to systematically identify their own earthquake vulnerabilities and to take appropriate action. These actions can range from securing bookshelves and waterheaters by homeowners, to elaborate efforts on the part of

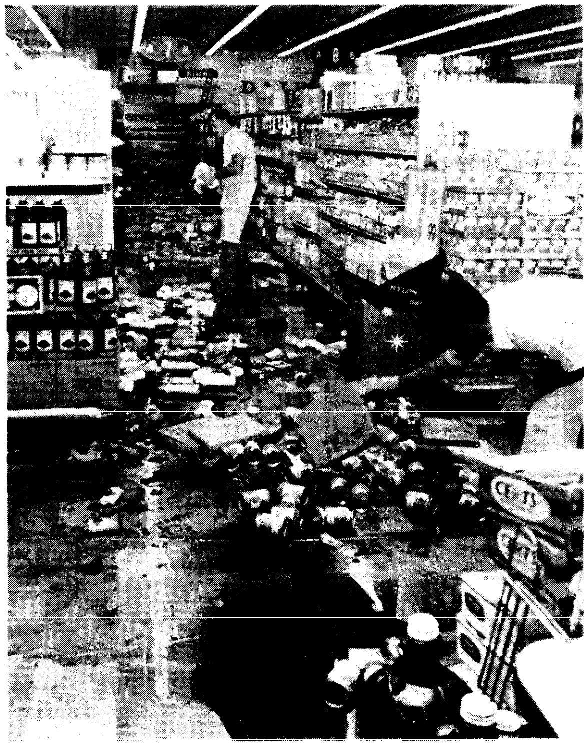
[11] Risk Engineering, Inc., "Residential and Commercial Earthquake Losses in the U.S.," report prepared for the National Committee on Property Insurance , May 1993, p. 17.

businesses, hospitals, schools, museums, and utilities to establish redundancies of power, services. computer databases, and the like.

Success in these efforts can work greatly to reduce the damage, injuries, and general chaos that may accompany earthquakes. The difficulty is that such efforts require diligent action on different fronts by different players, many of whom may care little about mitigation. Complicating matters is that most of these efforts require for their success that other measures be successful as well. For example, computer backups do little good if the computer resides in a building that collapses, and a single unsecured water heater can set an otherwise diligent neighborhood ablaze. Success thus depends on the community possessing a broad, active, and sustained level of public interest in mitigation.

■ Devising and Fostering Action

Once a community has decided on its choice of mitigation measures, it must put those measures into effect. The simplest action is to require (through regulation or mandate) that certain steps be taken. Such an approach, however, risks alienating the affected constituency (particularly in cases such as building retrofit or demolition, where high mitigation costs might be borne by a small group of individuals). Thus, in practice, many communities have chosen to develop alternative implementation strategies using financial or zoning incentives for mitigation, or (more weakly) through notices and disclosure laws warning potential renters or buyers of a building's noncompliance. Experience has generally shown that for success to be achieved, implementation schemes must be tailored to the particular political, socioeconomic, and geological conditions of a specific at-risk community, and that great pains must be taken to involve (as much as is possible) a broad-based constituency. Some possible approaches are illustrated in boxes 4-1 through 4-4. One potentially powerful implementation tool—the use of insurance to encourage the adoption of



Many earthquake losses cannot be eliminated through codes or other governmental measures, but require that individuals take steps to prepare.

seismic mitigation—is not discussed because of a lack of historical experience.

FACTORS AFFECTING IMPLEMENTATION

In the preceding section, some of the practical difficulties that arise in putting mitigation tools into effect are discussed. This section focuses on several underlying issues that more fundamental y influence implementation success.

■ Basic Problems

Communities interested in mitigation can encounter many frustrations in determining their level of seismic risk, in estimating their vulnerability to that risk, in assessing the short- and long-term economic consequences of mitigation, and in putting mitigation tools into effective action. Such difficulties arise even in the relatively straightforward process of improving life safety

BOX 4-3: Seismic Retrofit in Los Angeles, California

After California's San Fernando earthquake of 1971, in which buildings of unreinforced masonry (URM) construction experienced substantial damage, the nearby city of Los Angeles began considering ways of safeguarding its own URM building stock. Action was initiated in February 1973, via a city council motion to study the feasibility of seismic "building rehabilitation, " but eight years would pass before the landmark Los Angeles Seismic Ordinance finally became law. The twists and turns on the road to this ordinance—and the at times surprising impact it has had on local land-use patterns—illustrate some of the issues that can arise in the implementation of seismic retrofit programs.

Initial Action

Seismic retrofit action in Los Angeles was prompted by the San Fernando experience, by the 1971 passage of an earthquake hazards reduction ordinance in nearby Long Beach, and by the recognition that the city possessed many thousands of old, potentially vulnerable URM structures, many of which were extremely densely occupied. Concerns centered on life safety issues, with little priority given to minimizing earthquake-induced economic losses, and early attention focused on high-density, public-assembly buildings such as churches and movie theaters. This philosophy of targeting a select group of high-vulnerability structures quickly ran afoul of such community groups as architectural historians, who feared the demolition or visual modification of many of the city's historical landmarks, and groups such as the Association of Motion Picture and Television Producers, which felt that seismic ordinances would force the bankruptcy and closure of many marginal theaters (particularly since the proposed ordinances were combined with compliance requirements for structural, electrical, and fire safety codes from which the buildings had hitherto been exempt).

Vigorous community opposition to the proposed ordinances therefore led to the holding of public and city council meetings from 1974 through 1976. Following these meetings, it was decided to target only the most potentially catastrophic buildings: pre-1 934 URM assembly buildings that could contain over 100 occupants in the assembly areas. Because of continued concern over the financial implications of seismic retrofit (contemporary estimates placed retrofit costs at amounts comparable to the cost of an entirely new building), recommendations were also made that the retrofits be in part publicly funded by federal and state grants (for which lobbying efforts were initiated), low-interest loans, or tax incentives.

Work on establishing forms of financial assistance proceeded through 1976, but progress was Impeded by a combination of legal and engineering difficulties. One problem was that governmental assistance to churches or other sectarian-use buildings was deemed unconstitutional; another was a growing realization that very little was known about the true costs of seismic retrofit.

After three years without progress, an interim proposal in October 1976 suggested that the 14,000-odd buildings to be targeted by the eventual ordinance be prominently signposted as seismically hazardous By posting such information, the city hoped to invoke market forces for mitigation (by reducing market demand for vulnerable structures) before the start of seismic retrofit. This information-based proposal was strongly attacked by a host of citizen groups, among them the Hollywood Chamber of Commerce, apartment house owners, owners of commercial properties, and private attorneys. All expressed outrage and concern over possible effects on rents, property taxes, insurance rates, real estate sales, bank financing for renovations, lost jobs, and local economic development. Faced with this overwhelming opposition, the city tabled the proposal and redirected its efforts to the core components of the ordinance.

BOX 4-3 (cont'd.): Seismic Retrofit in Los Angeles, California

At this point in the controversy, studies were commissioned to determine the economic and social impacts of different proposals. Key issues included the breadth of the eventual ordinance (e.g., it was decided early on to cover a wide range of commercial and private building types, but to exempt single-family residences); the amount of time a building owner would be given to comply, the rapidity with which the program would be phased in and the prioritization given to different buildings and building types; and the type, availability, and impact of different financial assistance schemes. By 1978, these studies had identified specific concerns for the city council to address, among them: a continued lack of accurate retrofit cost estimates; a real possibility of substantial insurance premium hikes in the region, a significant likelihood of rent increases that would displace low-income residents; an insufficient municipal tax base for financial assistance (Proposition 13 had recently been passed); and an expectation that some businesses displaced during retrofitting would leave the city entirely.

Final Passage

With most of the concerns identified in the studies of 1977 to 1979 revolving around the economics of seismic rehabilitation, a breakthrough eventually occurred when three old URMs were found to stand in the path of a street-widening program. The city was persuaded to donate the three buildings for tests on the true costs of seismic retrofits. These tests, which were completed by 1980, showed retrofit costs to represent only about 20 percent of replacement costs—far less than had previously been suggested—and in so doing significantly weakened the economic objections to the proposed ordinance.

At last, after more lengthy debate, a seismic safety ordinance was formally adopted by the city on January 7, 1981—almost a decade after the initial impetus of the 1971 San Fernando earthquake. In its final form, the ordinance targeted all commercial URM structures and all residential URM buildings housing five or more dwelling units. After being notified by the city, owners of targeted buildings would have three years in which to bring their structures up to standard (this standard represents some 50 to 70 percent of the 1980 Los Angeles requirements for new construction). Buildings not brought up to standard would be demolished. To ease the impact on building owners and to facilitate bureaucratic execution, the ordinance allowed a one-year compliance extension should wall anchors (see chapter 3) be installed within the first year, and used a staggered notification schedule based on building type. Essential and high-risk facilities were to be targeted first, with lower risk structures to be dealt with later; as a result, some owners of low-risk buildings were not to receive official notification until 1988.

Impact of the Ordinance

From a seismic mitigation viewpoint, the Los Angeles Seismic Ordinance can be viewed as a success. Though the process has been more protracted than proponents might wish, a seismically vulnerable urban core is being prepared against the near-certainty of future earthquakes in the region. Should a damaging earthquake strike Los Angeles in the near future, it IS extremely probable that many Iives will have been saved by this measure. However, the ordinance has also generated side effects. Most notable has been the loss of low-cost housing, arising from owners raising rents in an attempt to recover out-of-pocket retrofit expenses. In addition, architectural and historic preservation has suffered-not because of building demolition (generally forbidden by historic building codes), but because of partial demolition, the removal of architectural ornamentation, and the filling in of windows.

(continued)

BOX 4-3 (cont'd.): Seismic Retrofit in Los Angeles, California

Perhaps the most surprising development has been a change in the overall appearance of some URM-lined streets, a change stemming from an unexpected interaction between seismic and fire safety regulations: noncompliance with existing fire safety codes has led many URM owners to close the upper floors (thus avoiding the cost of code compliance), and bring to compliance only the higher rent street level for use by commercial establishments (this partial vacancy is possible because fire safety codes need apply only to the occupied parts of a building). Because seismic retrofit must be applied to entire buildings—which means that vacant, nonproductive floors must be strengthened along with floors that are actually occupied—many of these URM owners have chosen to remove the upper floors entirely, leaving behind only single-story structures. Aside from aesthetic considerations, such removal further reduces the potential low-cost housing stock within the city's urban core.

WILLIAM SPANGLE AND ASSOCIATES, INC.

An unexpected side-effect of the Los Angeles seismic retrofit program was the partial demolition and conversion of multistory buildings into low, single-story structures

SOURCES: Daniel J. Alesch and William J. Petak, *The Politics and Economics of Earthquake Hazard Mitigation* (Boulder, CO, University of Colorado Behavioral Science, 1986), pp. 57-82; and Martha B Tyler and Penelope Gregory, *Strengthening Unreinforced Masonry Buildings in Los Angeles: Land Use and Occupancy Impacts of the L.A. Seismic Ordinance* (Portola Valley, CA William Spangle and Associates, Inc., 1990)

through building codes. When the goal is to reduce economic losses—which requires a much more comprehensive effort by both governmental and nongovernmental entities—the uncertainties are even greater.

Given these uncertainties, it is perhaps not surprising that many communities have encountered diffilculties in implementation. The problems are not insuperable in California-where earthquakes are frequent and severe enough to foster a desire for action—but even there one finds substantial variations in preparedness among different communities, and substantial difficulties persist in areas of retrofit and private or organizational activity. Outside California, matters are generally worse: in many hazardous regions, a relative lack of historical seismic activity produces a consequent lack of concern, so that even basic mitigation efforts languish.

■ Administrative Difficulties

In response to this inactivity, NEHRP has sponsored social science research on how and why communities act or fail to act. This research has shown that a number of forces conspire to weaken community will. Some of the difficulties stem from poor experience with existing mitigation ef-

BOX 4-4: Voluntary Retrofit in Palo Alto, California

While several communities in southern California have attempted mandatory retrofit and demolition programs to reduce the seismic vulnerability of urban centers (see box 4-3), the northern California city of Palo Alto has recently introduced a wholly voluntary, information- and incentive-based seismic retrofit program that is showing some early signs of success.

The origins of Palo Alto's voluntary program lie in two failed attempts at introducing mandatory, Los Angeles-style requirements. The first, a 1982 proposal targeting 250 unreinforced masonry, tilt-up (see chapter 3), and other vulnerable structures, succumbed to strong opposition from affected building owners and tenants. Following the defeat of this ordinance, the Palo Alto city council formed a broad-based citizen's Seismic Hazard Committee representing a range of public and private interests. This committee was intended to devise a second hazard mitigation plan that would reflect the concerns of the general community. However, the creation of the committee had the effect of greatly heightening community awareness of local seismic risk and hazard, with the consequence that the second proposal (in 1983) was far stronger than the first. This, too, went down in defeat—in part because of an inflexible retrofit timetable, and in part because proponents of the measure were hampered by extreme uncertainties regarding building vulnerability and the potential economic impacts of the ordinance. In light of these uncertainties, it was suggested that a voluntary program be instituted, one that would allow building owners to judge whether retrofit was economically justified, and one that would permit flexibility of approach and timing.

In 1986, a seismic ordinance was therefore passed in which no buildings were mandated for retrofit or demolition. The provisions of this ordinance areas follows: at-risk structures (particularly those with high occupancy) are identified and their owners given official notification. Following notification, building owners are required to contract with a structural engineer to evaluate building vulnerability and to suggest appropriate engineering fixes. Owners do not have to carry out the suggestions; however, they are required to inform building occupants in writing that an engineering study has been performed and that the results have been publicly filed with the city. In concert with the city's relatively high level of seismic awareness (fostered by the high education level of the citizenry, the work of the Seismic Hazard Committee, the presence of well-placed mitigation advocates within the local government, and extensive media coverage of earthquake disasters elsewhere), this notification is intended to affect rental and real estate prices in the city's highly competitive market. A March 1988 review of the program suggested that this market incentive is working as planned. To further increase the incentive, the city has also offered a zoning bonus, in which seismically upgraded buildings are allowed greater floor areas than is otherwise the norm. This bonus (again in concert with the city's strong economic health) also appears to be effective, to the extent that building owners who are unaffected by the program have sought (unsuccessfully) to obtain the bonus by having their own buildings included.

SOURCE: Philip R Berke and Timothy Beatley, *Planning for Earthquakes: Risks, Politics, and Policy* (Baltimore, MD: The Johns Hopkins University Press, 1992), pp. 63-81.

forts, which can suffer at the state and local level from:

- a lack of scientific and technical information in a form that local governments and private industry can easily use;
- overly stringent reporting, oversight, and approval requirements; and
- tasks that require more staff resources than are available (typically, implementation duties are assigned to but one or two persons in a state office).[12]

[12] VSP Associates, Inc., "State and Local Efforts To Reduce Earthquake Losses: Snapshots of Policies, Programs, and Funding," report prepared for the Office of Technology Assessment, Dec. 21, 1994.

More fundamentally, existing state and local efforts can suffer from a lack of hard information on earthquake risks and potential impacts. A recent survey of state activities has shown that **across the risk spectrum, studies of historical earthquake activity and assessments of current vulnerability are the two types of information essential to raising awareness, understanding, and commitment to seismic safety.**[13]

The Role of Advocates

Despite the difficulties that beset state and local mitigation efforts, considerable progress has been made by a number of concerned communities.[14] In many instances, this progress arises from the presence of well-placed mitigation "advocates"—energetic, often exceptional individuals in state or local government who adopt and push the cause of mitigation. Such advocates do not work in isolation. Rather, they can act as catalysts for action in communities where local political and socioeconomic conditions are conducive. Although their presence is not essential for action to occur, advocates can have an impact completely out of proportion to their numbers. Indeed, a number of cities owe the bulk of their mitigation progress to a handful of such individuals.[15]

Political Will

The importance of individual advocates, however, points out a larger problem besetting NEHRP: earthquake mitigation advocates (successful or not) are generally in the position of encouraging activity for which there is little initial enthusiasm. This reality has stern implications for efforts to reduce earthquake-related economic losses. While a few well-placed advocates can help convince governments to adopt building codes or land-use planning, they are less likely to create the groundswell of public action needed to substantially curtail future economic losses.

OTA's review of the implementation process has shown that effective mitigation depends on competent, committed action by a host of different individuals. This need is especially apparent in the case of private, small-scale, or systems-related efforts, which require that people design and implement their own mitigation schemes. Yet it is also true for the relatively straightforward use of building codes (i.e., an effective building code, adopted in full by the state or local authority, interpreted by engineers trained in seismic design principles, and enforced by experienced plan and code checkers working with the support of the local community) (see figure 4-1). To some extent, the many players in the chain can be persuaded or forced into action (at least for a while), but as a whole, implementation is greatly enhanced if there is an evident and sustained political will to support mitigation. Such is often not the case in the United States.[16]

Perceived and True Danger of Earthquakes

Nonfederal support for seismic mitigation suffers in part from the relation between earthquake risk and geography. At the federal level, interest in earthquake mitigation is sustained by a high prob-

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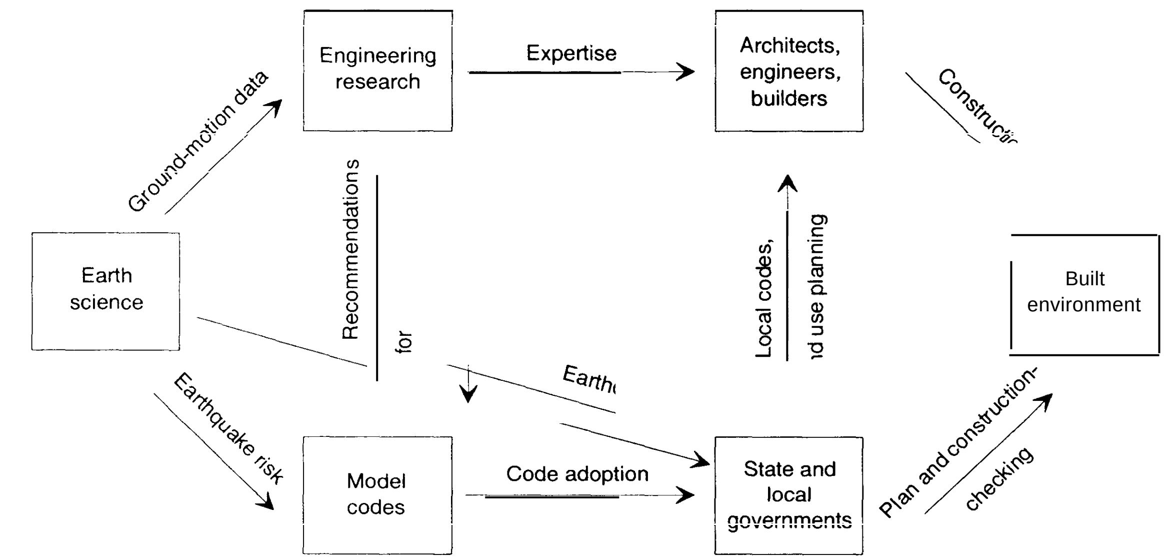
[13] Ibid.

[14] The report prepared for OTA indicates that California, Kentucky, Missouri, Utah, Arkansas, Washington, and Oregon devote particular attention to the formulation, adoption, and implementation of major policies. Ibid.

[15] Joanne M. Nigg," Frameworks for Understanding Knowledge Dissemination and Utilization: Applications for the National Earthquake Hazards Reduction Program," *A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987*, Walter W. Hays (ed.) (Reston, VA: U.S. Geological Survey, 1988), pp. 13-33; Philip R. Berke and Timothy Beatley, *Planning for Earthquakes: Risk, Politics, and Policy* (Baltimore, MD: The Johns Hopkins University Press, 1992), pp. 32-34; and U.S. Geological Survey, *Applications of Knowledge Produced in the National Earthquake Hazards Reduction Program: 1977-1987*, Open File Report 88-13-B (Reston, VA: 1988), pp. 20-22.

[16] Peter H. Rossi et al., *Natural Hazards and Public Choice: The State and Local Politics of Hazard Mitigation* (New York, NY: Academic Press, 1982), pp. 40, 71.

FIGURE 4-1: Implementation Steps and Key Players for the Application of Seismic Codes



NOTE Steps and players will differ for other types of mitigation measures

SOURCE Off Ice of Technology Assessment, 1995

ability of damaging seismic activity occurring within federal jurisdictional borders. To the extent that California bears the largest share of the country earthquake hazard, California state interest in earthquakes is also reasonably strong (it is not coincidental that California's mitigation efforts frequently surpass those of the federal government). For the rest of the country, however, the risk[17] of earthquake activity in any one state is considerably less than the nationwide risk borne by the federal government, and everywhere the local risk declines further when one considers the smaller governmental or organizational units. At the extreme is the plight of the individual building owner in a region such as the Northeast. This individual owns a structure that might never experience a damaging earthquake. If an earthquake occurs, the building may or may not collapse. If it does collapse, it is not certain that retrofitting would have saved it.

In short, while the federal government may have a legitimate interest in encouraging all building owners in the country to consider retrofits (on the assumption that at least some of those retrofits will do some good), an individual owner may see very little reason to embark on a costly action whose benefits are long term and uncertain. The owner lack of interest maybe based on a very rational analysis of costs and benefits, but can also be influenced by the short time horizon frequently observed in analyses of consumer decisionmaking (sometimes expressed as a high consumer discount rate), an influence that has been well documented in issues of energy efficiency,[18] and which has relevance to hazard mitigation.[19]

[17] *Risk* is used here as total exposure or potential for damage in an earthquake.

[18] See, e.g., U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency,* OTA-E-518 (Washington, DC: U.S. Government Printing Office, May 1992), chapter 3.

[19] H. Kunreuther, "The Role of Insurance and Regulations in Reducing Losses from Hurricanes and Other Natural Disasters," *Journal of Risk and Uncertainty,* forthcoming.

With perceived risk at the individual level often very low, one can attempt to increase it through skillful use of the media and educational outreach. That the media can have significant impact on earthquake awareness is unquestioned, and history has shown that extensive media coverage in the aftermath of a damaging earthquake creates a temporary "window of opportunity" for rapid mitigation progress.[20] The importance of these windows—and the unpleasant reality that mitigation progress can easily stall after the window closes[21]—has prompted research on how one may best create a permanent perception of risk. Results have thus far been mixed—for example, some studies show that people already overestimate the risk of rare events such as earthquakes,[22] while others suggest that low probability risks tend to be ignored.[23]

Role of NEHRP

Given the general lack of sustained public support for mitigation, why does NEHRP depend so heavily on the unforced adoption of mitigation measures by nonfederal entities? In large part this dependence stems from the scientific circumstances that surrounded the program's birth. In broad terms, NEHRP was created during a period of optimism over the practicability of accurate earthquake prediction, and its original program mission (which specifically cites prediction as a goal) reflects that optimism. At the time of NEHRP's founding, the earth sciences had just emerged from a sweeping and profound revolution, one comparable to Darwin's theory of evolution in its scope, impact, and ramifications. This revolution was the advent of modern plate tectonic theory—a conceptual picture of the world that, through the 1960s and early 1970s, succeeded in tying together a host of previously unexplained and seemingly unrelated phenomena from across the earth sciences. Seismology—the study of earthquakes and earthquake-related phenomena—played an integral role in the development of plate tectonic theory; in turn, plate tectonics offered a simple unifying framework for understanding why, when, and where earthquakes should occur. The decade of the 1970s was thus one of extraordinary excitement in the earth sciences, and in this climate it was felt that short-term earthquake prediction, if not just around the corner, was at least conceivable, and that steady improvements in long-range earthquake forecasting would come with research.

The significance of this optimism from a policy standpoint is that it favors a mitigation strategy in which federal incentives for action are perceived as unnecessary. As we have seen, uncertainties in the timing, location, and severity of future earthquakes hinder both the acceptance and the execution of mitigation programs by nonfederal entities. Successful earthquake prediction, in removing this uncertainty, improves matters by providing a clear motivation for action and by delineating the intensity and geographic scope of the necessary mitigation, thereby constraining the cost.

In effect, a vastly refined foreknowledge of how, when, and where earthquakes occur can arguably be used to create both the desire and the expertise for the implementation of mitigation measures. In keeping with this philosophy, NEHRP was given neither regulatory teeth nor the authority to provide substantial incentives for mitigation. Instead, the program was intended to create a font of knowledge from which nonfederal

[20] U.S. Geological Survey, see footnote 15, pp. 27-28.

[21] Berke and Beatley, see footnote 15, p. 178.

[22] Andrew Coburn and Robin Spence, *Earthquake Protection* (Chichester, England: John Wiley & Sons, 1992), p. 315.

[23] Daniel J. Alesch and William J. Petak, *The Politics and Economics of Earthquake Hazard Mitigation* (CO: University of Colorado, Institute of Behavioral Science, 1986), p. 142; and Dennis S. Mileti et al., "Fostering Public Preparations for Natural Hazards: Lessons from the Parkfield Earthquake Prediction," *Environment*, vol. 34, No. 3, April 1992, p. 36.

authorities and the private sector would eagerly draw.

Although it is debatable whether NEHRP would have attained its societal goals even with widespread success in earthquake prediction (given the implementation difficulties discussed above), the fact is that prediction is not likely in the near future. This development is not the fault of the program. In fact, it is NEHRP-sponsored research that has begun to reveal just how complex, unpredictable, and variable earthquakes and their effects really are. Because of NEHRP we now know far more about earthquakes and far more about the structures and techniques that can withstand them. However, with this understanding comes a better appreciation of how deep and stubborn are the remaining uncertainties—uncertainties that work against the nonfederal adoption of mitigation measures.

HOW MATTERS MIGHT BE IMPROVED

The preceding sections have shown that implementation difficulties hinder both the adoption and the execution of seismic mitigation programs; these difficulties largely reflect the economic and political cost of mitigation as seen against a backdrop of uncertain seismic hazard and vulnerability. In the current NEHRP structure, federal activities to promote mitigation consist largely of outreach, media, and educational programs; such efforts may be expanded, or they may be supplemented by more aggressive implementation tactics (see chapter 1). Here, OTA suggests a range of directions that can improve mitigation efforts.

The implementation needs of California are largely different from those of the rest of the country. Within California, continual seismic activity in a heavily urbanized state has led to significant public and governmental awareness of earthquake risks and hazards. This awareness has resulted in California leading the country in mitigation and preparedness efforts. Because California already has in place a basic mitigation framework of new building codes, selective policies of land-use planning, and active public outreach programs through schools and the media, the main implementation issue is execution, rather than adoption. That is, although some adoption problems remain (notably, the retrofit of "pre-code" buildings that do not comply with the latest building standards), for the most part one can concentrate on expanding and optimizing the mitigation efforts that are already in play.

In contrast, regions outside California display a broad spectrum of mitigation activity, ranging from encouraging progress in some communities of the Pacific Northwest, to low or nonexistent activity in many parts of the East Coast, central United States, and Intermountain West. For some of these areas, earthquake severity and timing are such that seismic concerns are reasonably seen as low priority (e.g., Boston). In others, potentially high risks are masked by relatively short histories of urban settlement and a relative absence of frequent, moderate-level seismic activity (e.g., the Intermountain West). In concert with the extreme levels of scientific uncertainty that seem to surround non-California earthquakes, these factors have greatly inhibited the adoption of many mitigation measures.

Thus, in basic terms, one would hope to improve program *execution* in California while encouraging program *adoption* elsewhere. Efforts to achieve these aims can be made in each of the three NEHRP components: earth science, engineering, and implementation.

Earth Science Research Measures

Earth Science: Reducing Loss of Life

Earth science research efforts that can improve life safety in future earthquakes fall into two broad categories: basic research that will reduce the likelihood of "surprises" in the future size, location, and timing of severely damaging earthquakes (and in so doing, increase the likelihood that mitigation measures are adopted); and more directed, microzonation-style studies to identify localized troublespots. Both categories are of use throughout the country, although their roles vary subtly according to geography.

In areas where implementation is currently weak (i.e., much of the country outside of California), reductions in loss of life (and economic losses) require that seismic building codes and other mitigation measures be adopted by at-risk communities. **Because great uncertainties over earthquake location, severity, and timing act as a disincentive to action, the earth science priority here is for basic research that can better zero in on when, where, and how strongly an earthquake will strike**. This research must not only delineate where earthquakes are likely to occur (information that increases the perceived benefit of mitigation), but also identify areas of relative safety (which reduces the geographic extent—and thus cost—of mitigation).

Where there exists some degree of interest in seismic mitigation, the potential importance of microzonation-style research grows. In localities where the earthquake danger is recognized, such research allows communities to sidestep opposition to broad-based mitigation by narrowly targeting exceptionally hazardous sites (this is the approach taken by Utah's Salt Lake County Natural Hazards Ordinance, discussed in box 4-2). More mitigation-friendly locales will likely use such research to help prioritize efforts in seismic retrofit and demolition; to identify situations in which land-use planning is the most effective implementation option (i.e., places where no reasonable amount of engineering can overcome the effects of catastrophic liquefaction, landslides, or tsunamis); and to optimize building code provisions for the characteristics of future ground motions.[24]

Earth Science: Reducing Economic Losses

Although the importance of earth science research for life safety is clear, its role in minimizing economic loss is somewhat less so. This uncertainly stems from our lack of understanding of the true sources of earthquake economic loss.

On the one hand, successful earth science research can reduce future economic losses in those regions where mitigation activity is relatively weak. Where mitigation measures are hampered by uncertainty over risk and hazard, refined earthquake forecasts can encourage their adoption. In addition, microzonation research can allow otherwise reluctant communities to direct their efforts to geographically limited locales, thus fostering adoption where there would otherwise be none. In both cases, research can lead to loss reduction through the encouragement of basic mitigation activity.

In regions where mitigation measures are already in place, however, continued earth science research plays a more uncertain role. Because such regions typically experience high seismic activity (e.g., southern California), sheer prudence dictates that basic seismic research and ground-motion studies be continued so as to reduce the likelihood of major surprises in earthquake location and severity (surprises that can leave even a diligent community unprepared for a future calamity). However, in the absence of such surprises, there is the possibility that continued research will beget diminishing returns. At issue is the true source of earthquake economic losses: if the bulk of such losses stem from episodes of major damage, then refined earthquake and microzonation forecasts can reduce losses by permitting better targeting of vulnerable structures (particularly if the research is directed toward lifeline survivability). However, if the majority of earthquake losses stem ultimately from moderate-to-minor ground-shaking damage distributed over a wide area, then efforts to pinpoint local trouble spots (as well as to refine estimates of earthquake timing and location) will not address the major source of economic loss. **Uncertainty over the true origins of earthquake-induced economic**

[24] Damage in the 1994 Northridge quake indicates that even moderate earthquakes can subject buildings to stresses far greater than have been expected, and one must assume that larger quakes possess a similar potential. Credible ground-motion estimates, derived from microzonation-style modeling and from data collected in actual events, are therefore essential to writing effective building codes. However, such estimates will be of use only if actively transmitted to the engineering community in a manner that recognizes the need for codes to be stable over time.

losses therefore impede discussions of earthquake loss reduction, and remain an important avenue for social science research.

Engineering Research Measures

Engineering Measures: Reducing Loss of Life

From an implementation perspective, improved life safety can arise from engineering research if retrofit costs are brought down, and if better tools are devised to assess building vulnerability.

Particularly in California, where new construction is reasonably well handled by codes,[25] measures to save lives will center on older structures, particularly buildings of unreinforced masonry. Although many factors inhibit the systematic retrofitting of URMs and other noncomplying structures, a major obstacle to retrofit action is simply cost. Successful research into more cost-effective retrofit techniques—particularly if the techniques can be shown to reduce post-earthquake repair bills dramatically—can therefore make retrofit programs more palatable both to local policymakers and to building owners.

Opposition to retrofit programs can be further reduced if it can reliably be determined what buildings do *not* need to be retrofitted. For example, not all URM structures display the same vulnerability to earthquake damage, and a means of distinguishing the most vulnerable from the least can permit a more selective targeting of structures. Ongoing efforts to develop an analytic means of making such distinctions can therefore enhance program effectiveness while reducing the number of affected building owners and occupants.

Engineering Measures: Reducing Economic Losses

As noted above, current building codes focus on structural issues while giving little attention to nonstructural and contents damage. Because the latter kind of damage can generate most of the economic losses that accompany damaging earthquakes, research into effective, low-cost methods of reducing such damage might yield substantial rewards.

It is unclear, however, how to best incorporate nonstructural and contents damage concerns into current building codes. One difficulty is that such damage is often hard to proscribe in the language of a prescriptive code (e.g., a code cannot easily specify what steps a computer software company must take to safeguard its data and records, nor can it order individuals how to arrange furniture, bookshelves, or cooking equipment). Because of this limitation, one approach could be to replace prescriptive building codes with performance-based standards (i.e., codes that provide great flexibility of execution while requiring minimum standards of seismic performance). Such an approach has been adopted with some success in the construction of California hospitals, which are required to maintain functionality in the aftermath of a damaging earthquake (however, these codes are somewhat controversial in their need for painstaking execution). By defining design options appropriate to different levels of safety or performance, engineering research may increase the odds that performance-based codes attain a wider use.

A second approach to reducing economic losses would be to concentrate on the indirect effects of earthquake damage. In particular, because the federal government maintains some authority over lifeline systems (e.g., transportation and energy), a potentially significant avenue for economic loss reduction lies in the "hardening" (i.e., strengthening and introducing redundancy) of lifelines and vital response systems to reduce indirect losses and improve post-earthquake recovery. Such a move would be assisted by research into measures such as the preservation of potable and firefighting water systems, or the use of automatic shutoff devices on natural gas lines.

[25] Subject to the limitations noted in this chapter, including problems of enforcement and limited coverage of economic damage.

Direct Measures To Improve Implementation

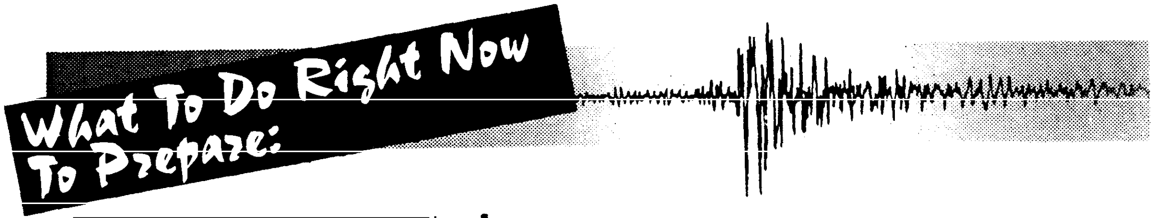
More direct efforts to improve implementation will primarily involve education and outreach, technical assistance to nonfederal governments and organizations, and social science research into the nature of implementation bottlenecks. These efforts can be applied to the current implementation framework, or as preparation for a more vigorous federal mitigation role.

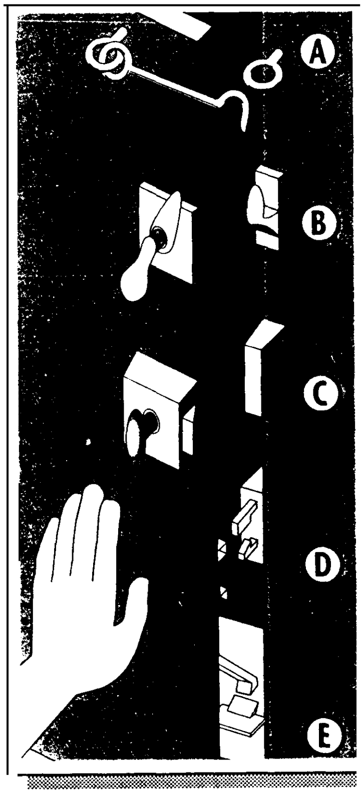
Actions that may assist implementation within the current framework include the following:

- Because individual local advocates and concerned professional organizations can play a powerful role in fostering and maintaining community interest in mitigation, efforts to create or assist advocates are of great potential impact. The federal government can assist advocates in this area by: ensuring that advocates have access to the latest information and educational materials on earthquake risks, supporting community activities as funding permits, or supplying direct technical and educational assistance to local or state governments.
- The more publicity there is concerning earthquakes, the more likely it is for individuals to become advocates. Thus media and public outreach activities can have a powerful indirect effect, both in fostering the appearance of advocates and in creating a supportive environment in which they may act. Public interest in earthquakes generally depends on how recently a major quake has occurred, but preparing outreach materials to take advantage of disaster windows is a prudent measure. Such outreach is relatively inexpensive and potentially productive, although in places where destructive seismic activity is extremely infrequent (e.g., the U.S. east coast), it is unlikely to create a surge of local activity.
- Research into the political and social science of mitigation success and failure can assist implementation by identifying stumbling points (e.g., factors hindering code enforcement) in the implementation process. Such research will not likely be undertaken without federal support.
- Perhaps the most promising implementation activity is to assist communities in their efforts at understanding risk, vulnerability, costs, benefits, and mitigation options. Workshops, conferences, and forums have been and will continue to be useful in disseminating such information, but strong efforts should be made to assign hard numbers to the predictions. In particular, communities must be given analytic tools for estimating likely losses in the event of a future earthquake, and credible means must be developed to predict the likely benefits of mitigation. At present, it is difficult to quantify these basic parameters, and it is this absence that perhaps most inhibits vigorous action at all mitigation levels.[26]
- In addition to supplying such informational assistance to at-risk communities, the federal government might wish to offer more direct technical aid. This aid can take the form of supplied expertise (e.g., mitigation efforts in the Salt Lake County of Utah were greatly enhanced by a three-year federal grant for hiring an in-house county geologist—see box 4-2), or through programs to assist in the education and training of engineers and design professionals in the principles of seismically resistant construction.
- To complement activities on the seismic front, efforts can be made to incorporate seismic implementation into a larger “all-hazards” framework. Much of the nonstructural preparation required for seismic mitigation (e.g., predisaster emergency planning) is useful in the event of fire, flood, wind storm, or other natural disasters, and can thus gain in political and eco-

[26] The Federal Emergency Management Agency is currently supporting development of a computer-based tool to assist communities in loss estimation, a promising endeavor that may considerably aid future implementation efforts.

HUMBOLDT EARTHQUAKE EDUCATION CENTER





LATCHES

For manv residents of the North Coast a large financial loss will come if the doors of kitchen cabinets are shaken open, throwing contents to the floor. A few dollars spent now can prevent most of that loss.

In choosing a latch, consider looks and ease of use, The standard hook and eye(A) is an inexpensive and secure latch, but you may not close it every time you enter the cabinet because it takes extra effort to do so. A child-proof catch (E) prevents a door from opening more than an inch or two. These catches close automatically, but they require an extra action every time you open the door.

Some standard types of secure latches mount on the surface of the door (B, C). Latches are available that mount inside the door (D), hold the door firmly shut and open by being pushed gently inward. These are marketed under names such as push latch, touch latch, or pressure catch. If you cannot find these latches, ask your hardware dealer to order them for you.

Protect Your Belongings

Falling objects and toppling furniture can be dangerous and expensive to replace or repair.

- Move heavy items, such as pictures, mirrors or tall dressers, away from your bed.
- Secure tall furniture and bookcases with lag bolts to wall studs. Add lips to shelves to prevent costly items from sliding off. Be sure adjustable shelves cannot slide off their supports.
- Put latches on cabinet doors, especially at home in your kitchen and at work or school laboratories
- Fasten heavy or precious items to shelves or tables. Secure file cabinets, computers, televisions and machinery that may overturn during an earthquake.
- Store potentially hazardous materials such as cleaners, fertilizers, chemicals, and petroleum products in appropriate containers and in sturdy cabinets fastened to the wall or floor.
- In your office, be sure heavy objects are fastened to the building structure and not just to a movable wall. Ask a carpenter or an electrician to determine whether light fixtures and modular ceiling systems are securely fastened.
- Be sure your water heater is fastened to the wall studs and that all gas heaters and appliances are connected to the gas pipe through flexible tubing. If you use propane gas, be sure the storage tank is secured against overturning and sliding.
- Secure your wood stove to wall or floor studs. Make sure you have a fire extinguisher close at hand.
- Check with your school officials to be sure they have taken similar precautions.

6

Outreach and education materials, such as this pamphlet on safeguarding household effects, can both foster and guide mitigation efforts.

nomic attractiveness when viewed in a larger context.

- Lastly, consideration can be given to making NEHRP less of a purely voluntary, information-driven program by attaching strong incentives for action and regulatory or economic penalties to inaction (e.g., through changes in federal disaster relief or insurance). These options, which are discussed in chapter 1, can also act as a tool for enforcement (e.g., by using pre-mortgage inspections to ensure building code compliance).

All of the above efforts require insight into the many political, economic, social, and practical forces that shape the implementation process. It should be reemphasized that the current understanding of these forces is by no means complete. Social science research into the behavior of communities and individuals is thus of considerable importance—all the more so if substantial changes to current policy are being considered (e.g., the possible use of mandatory earthquake insurance to foster seismic mitigation). Ongoing NEHRP-funded social science research has already illuminated many of the factors affecting implementation within the current NEHRP framework; this effort might profitably be strengthened or extended. In particular, substantial social science knowledge gaps remain that hinder efforts to improve NEHRP. Chief among these are the following:

- How might individuals respond to financial incentives (such as insurance) for implementation?
- Does the current de facto insurance framework (federal disaster assistance) inhibit state, local, and private implementation efforts, and if so, to what extent?
- Where do the true bottlenecks occur in the enforcement process for seismic building codes (e.g., to what extent does the trouble lie in on-site building inspection, in plan checking at the design stage, or in unexpected variability in construction practices and standards)?
- Will different parts of the country respond differently to proposed implementation strategies, and if so, what regional variations are to be expected?

Successful research into these matters will greatly improve action within the current implementation framework, and will be critical to any efforts at extending program scope.