MANAGEMENT OF EARTHQUAKE SAFETY PROGRAMS BY STATE AND LOCAL GOVERNMENTS

DELBERT B. WARD

This paper deals with fundamental concepts for management of earthquake hazards and associated earthquake safety programs at state and local levels of government. The focus of the paper is upon recognizing and narrowing a gap which the author believes to exist between earthquake hazards information (essentially research data) and applications of the information (public policies for implementation of hazards reduction methodologies).

BACKGROUND

That natural hazards can be managed for the overall benefit of our society is a notion accepted by most of us. We believe--correctly, I think--that life loss, injuries, and property losses can be reduced through prudent pre-event practices and effective deployment of resources when disasters occur. Emergency management is an institution of government that has evolved over the past two or three decades whose primary purpose is to articulate and carry out a broad array of activities directed to loss prevention and/or loss reduction due to extreme events--both natural and man-made.

Emergency management practices traditionally have separated into several phases, due no doubt to the time-related character of the activities. For this discussion, we refer to four such phrases--preparedness, mitigation, response, and recovery. Other divisions have been used, but the variations have no significance to our purposes here.

Beyond these time-related characteristics that are common to nearly all emergency management activities, the similarities among the risk reduction activities appear to end for the various hazards. Each type of natural hazard-- earthquakes, tornadoes, hurricanes, and floods--derives from a different sort of natural phenomenon, has different physical characteristics that create risks to life safety and property, and, consequently, requires different methods for effective control (management) of the risks.

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If the reader accepts that there are physical distinctions between the several types of natural hazard named above, then it is useful to examine briefly the implications of these distinctions with respect to the time-related emergency management activities of preparedness, mitigation, response, and recovery. Although management concepts for the hazards may be similar in some cases, the specific risk-reduction activities are quite different for each type of hazard. Moreover, the importance (priority) of the types of action with respect to the end goal of risk reduction seems to be different for each type of hazard.

For example, for a variety of reasons control of losses due to a hurricane requires different emphasis upon preparedness and recovery actions than does control of losses due to an earthquake, In the case of hurricanes, preparedness actions based upon pre-event warning are possible; mitigation is largely a matter of siting considerations; and response activities can be coordinated to occur even during the event. On the assumption that life safety is the paramount objective, preparedness based upon pre-event warning is emphasized.

Riverine flooding, too. requires a different emphasis for effective loss control. Once again, preparedness actions can be based upon pre-event warning, but effective loss control requires that emphasis be placed upon mitigation actions.

Earthquake events, in contrast, say, to hurricanes happen without warning and are of very short duration--a few minutes at most and hardly enough time to do anything more than duck. Current technology does not allow short-term prediction of the events, although regions of greater earthquake potential and even long-term (several years to several decades) speculations about impending events are within current technical state--of-the-art capabilities. Moreover, we presently do not know how to control (eliminate or soften the occurrences) of the earthquake events. Accordingly, emergency management methods presently are limited to (1) reducing the effects of the earthquake upon buildings and people--mitigation--and/or (2) providing recovery services--picking up the pieces, so to speak--after the events.

Either of the above types of emergency management actions will help to reduce earthquake losses to some extent, but mitigation assuredly can be the most effective of the two types of actions. Mitigation can eliminate losses in some cases and certainly can reduce losses in most cases whereas recovery actions can only attempt to contain the extent of losses and restore essential lost facilities and services.

These differences among the hazards lead to differences in management methods that must be acknowledged and met. This entails, first, recognizing the characteristics of each type of hazard and their consequent effects upon us. The appropriate kinds of management activities and the relative effectiveness of each activity then can be tailored to the type of hazard. We now take the specific case of earthquake safety for elaboration upon this point.

The argument developed above aims essentially at making a strong case for mitigation as the most effective means available to us today to reduce earthquake losses. If this argument is accepted, than we are left with the task of defining mitigation for earthquake safety and, consequently, with describing the implication that a mitigation approach has with respect to emergency management methods.

Mitigation of earthquake risk is accomplished almost entirely through control of the "built environment." Earthquakes themselves rarely if ever kill or injure people directly. Rather, they displace buildings, building components and other elements of the build environment such as highway structures, dams, water and electric systems, etc., which in turn may jeopordize life safety and cause great social and economic inconvenience. By controlling the quality of the things we build and by selecting construction sites less likely to feel hazardous earthquake effects, it is possible to achieve reduced life loss, reduced injuries, and reduced property losses. None of the other emergency management phases accomplish this to any degree even though the phases are necessary parts of a comprehensive comprehensive emergency operation.

Construction of the built environment is controlled by construction regulations, codes, zoning ordinances, siting evaluations, and good design practices. Most of these controls already are a part of every community's governance mechanisms. It is through actions that impact upon these processes of control that earthquake mitigation must be accomplished.

The control procedures indicated in the paragraph above are implemented through organizations which have not been dealt with to any great extent by traditional emergency management agencies in the past. Even when emergency management agencies have worked with these existing infrastructures, such as land-use regulatory agencies for flood mitigation efforts, the physical and technical difference between earthquakes and the other hazards allow very little carry-over of learning experiences. It seems clear to this author that effective earthquake hazards mitigation actions will require new liaisons to be forged between emergency management personnel and organizations that control or regulate construction of the built environment.

These new liaisons likely will be somewhat different than the liaison formed in traditional emergency management activities of the past, most notably the civil defense program of the past that dealt with problems not faced by many existing agencies of government. In the case of earthquake mitigation, we find that existing agencies already are in place which have responsibility for controlling the quality of the built environment. It is most likely that these agencies will insist upon preserving their regulatory jurisdictions when earthquake hazards mitigation processes are introduced. Under these circumstances, it is even questionable whether or not the traditional emergency management agency has a role with regard to earthquake hazards mitigation.

Severe flood threat in the State of Utah during the past two years illustrates this point. Having experienced excessive springtime run-off in 1983, with consequent flooding of stream beds and mudslides, Utah counties and cities undertook hurried public works improvements to mitigate similar future problems. Without exception, these prejects were managed by existing full-time public works administrators and flood control personnel. These personnel are not part of the state's emergency services agencies and work independently of those agencies. Although coordination between the public works agencies and the emergency services agencies occurred, this was primarily with respect to preparedness and recovery actions. Mitigation actions were carried on by the public works agencies.

Mitigation for earthquake safety seems to have silmilar restraints in the sense that there are existing governmental agencies responsible for control of the quality of the built environment. Once public policy has been set for earthquake hazards mitigation, as was the case for mitigation of flooding, the existing agencies having jurisdiction will proceed to carry out the policy mandates, I believe.

One implication of the above observation is that the problem of achieving effective earthquake safety is not so much one of management, but rather is one of persuading a reticent public sector of the need for a sound public policy for earthquake safety. If the public commitment is clear in this regard, the machinery is available in government to carry out the mandate.

THE GAP BETWEEN TECHNOLOGY (RESEARCH) AND APPLICATIONS

Knowledge about the behavior of earthquakes, although far from adequate for the scientific community, is quite adequate today for applying earthquake risk mitigation techniques to the built environment. The literature on earthquake physical characteristics and on techniques for construction of earthquake-resistant facilities--buildings, transportation systems, dams, utilities systems, etc.--is extensive. Sufficient technical information can be assembled to allow preparation of earthquake risk evaluations which, in turn, allow estimates of possible earthquake losses to be prepared. One also can ascertain the types of likely construction failures associated with the losses.

With such information, one can suggest modifications in siting practices and construction methods that are most effective for saving lives and most cost-effective for the community. Indeed, these kinds of data have been assembled in a variety of forms and for a variety earthquake conditions. As well, some of the data are even assembled for different regional earthquake conditions.

Despite this wealth of information, there has not been widespread application of earthquake risk reduction measures in the private or public sectors of this nation. Except in California, public apathy about earthquake risk prevails, and local governments resist adopting public policies that would encourage application of risk reduction. There is a large gap between the available technical information and application of earthquake mitigation measure.

Credit is due to the federal government which has been actively promoting improved earthquake safety practices and encouraging development of emergency management tools to deal with the hazard. However, these efforts have aimed largely at making the federal government a helpful partner with state and local government in such matters. In general, mandated federal requirements for earthquake safety do not exist.

Given this present working arrangement, it should come as no surprise that the federal efforts can be no more effective than the efforts of the other half of the partnership--state and local government. It is at these state and local government levels that earthquake safety has failed to receive the attention that I believe is warranted--the exception again being California. Other states and local governments occasionally give verbal support (motherhood statements) to earthquake safety. Rarely have they set forth public policies to bring about the needed changes.

Yet, control and regulation of construction of the built environment lies almost entirely within the domain of state and local government in this nation. The federal government has not usurped this prerogative. State and local governments zone the land; they adopt building codes; and their personnel design many of the public facilities, such as transportation systems, water supply systems, waste systems, and even some utilities systems. Mitigation of earthquake risk, therefore, apparently must be accomplished through these existing institutions and processes of state and local governments. For them to do so, however, the policymaker must be convinced that the public interests are well served. At this time, they do not appear to be convinced.

Some forward motion in improved earthquake safety practices has occurred through the private sector in ways that generally are independent of government. Recognition of this motion is pertinent to our discussion of the gap between technology and applications because it provides further insight into the reasons why the gap occurs.

Construction practices are influenced, sometimes even controlled, by groups besides governmental regulatory agencies. Two such groups are the design professionals and developers of construction codes and standards. The design professional--the architect or engineer--always has the option of specifying construction of a quality that exceeds the minimum requirements of adopted codes and standards. To some extent this has occurred, although randomly, throughout the nation with respect to earthquake-resistant construction. However, without a clear statutory mandate, designer attentiveness to earthquake hazards mitigation will continue to be random and susceptible to client pressure that the facilities meet only minimum standards of performance.

The national model building code organizations and similar other groups who develop construction codes and standards also have great influence over construction quality. This occurs because the common practice is that state and local governments often adopt these codes as their standards or regulations. Yet, these codes and standards essentially are developed outside of government by mixes of design professionals, building officials acting independently of their agencies, product representatives, and trade organizations. Hence, it is possible to achieve improved earthquake safety practices by including appropriate standards in the codes which eventually get adopted by most, but not all, states and local governments. The process for introducing new concepts into codes and standards is long and tedious, but the avenue is available to us.

Although forward motion in earthquake safety practices has occurred through the two types of groups described above, the efforts have been constrained by inadequate knowledge in application. It is one thing to gain appropriate language in the codes and standards; it is quite another thing to interpret and apply the recommendations in actual construction conditions. Broader and better focused training is essential if the design professionals and the standards are to be a primary means for achieving improved earthquake mitigation practices.

CAN EDUCATION NARROW THE GAP?

In this paper, the existence of a gap between our level of technical knowledge about earthquake hazards and a public willingness to apply the available knowledge to loss reduction practices has been emphasized.

In the author's experience with earthquake safety, this lack of public willingness to utilize available knowledge is the major reason for the lack of public policies that are needed to promulgate effective earthquake loss reduction actions. Public apathy toward the problem is manifested by the absence of political commitment by state and local governments to deal with the situation in any significant way.

Although the public generally seems to have knowledge about earthquake hazards and associated risks to life and property, albeit sometimes incomplete and inaccurate, this author's view is that there is adequate knowledge and information for the public to take risk reduction actions if only the will to do so were present.

Several conclusions can be drawn from this observation. One can only speculate as to which, if any, of the conclusions are accurate, and, of course, none of the conclusions may be valid if the underlying premise lacks validity--namely, that a public commitment is missing. Five possible conclusions are listed below and then discussed briefly:

1. The risks posed by earthquakes are not believed to be sufficiently great to warrant doing any more than presently is being done to control losses.

2. Earthquake risks are perceived to be too narrowly limited to just a few population centers (earthquake regions) to justify any public policies aimed at abating the problems.

3. In an economic, cost-benefit sense, earthquake risks are perceived (or actually are) lower than the costs of risk reduction.

4. Potential victims of loss believe that governments (federal, state, and local) will provide the resources to recover any losses. (This conclusion fails to be responsive to the possibility of life loss and injury.)

5. The public simply does not know enough about earthquake risk to give the problem much attention and so does not care.

If Conclusion 1 is accurate, then efforts to broaden the public concern for earthquake safety may be the equivalent of "beating a dead horse." If Conclusion 2 is accurate, then the case can be made for strengthening public information and education programs. If Conclusion 3 is accurate, then some research efforts ought to be shifted to economic analyses to confirm or reject the perceptions. If Conclusion 4 is accurate, then either some changes in governmental assistance policies ought to be made so that individuals and local governments are held accountable for their failure to act prudently or governments should redirect their emergency management functions to preparedness, response, and recovery and abandon mitigation efforts for which the cost is borne by others. If Conclusion 5 is accurate, then intensified efforts in public education seem to be warranted.

This author is not aware of any studies that aim at verifying or rejecting the conclusions suggested above. Until that is done, we can only speculate about which among them may be the more accurate. We therefore cannot direct educational resources to deal with a situation which is inadequately identified.

That the public is not ready at the present time to make policy commitments to earthquake safety is the best that can be said. While those of us who seek improvements in earthquake safety can point to a number of individuals and organizations around the nation who feel the same as we do, it is a sad fact that the numbers of us have not grown significantly in recent years nor have we achieved much in the way of public policy changes.

Enough has been said in the negative. The remaining questions are whether or not education and training can help to change this situation and, if so, what might be the form and focus of this education and training. This author's view is that educational efforts in earthquake safety must continue regardless of public receptivity. To do otherwise would reduce, in effect, the level of present knowledge about earthquake hazards and risk reduction for we would fail even to provide an opportunity for follow-up generations to inform themselves. Old timers eventually are replaced by new faces. It is the natural way of things. We would do a disservice to the younger generations by failing to provide for the transfer of our knowledge.

What kind of education, then, and for whom? Sidestepping for a moment the lack of public commitment to earthquake risk reduction, need for at least three types of education and training can be identified in the comments made in prior portions of this paper: training of emergency management personnel that aims at clarifying the new types of liaisons needed for earthquake risk reduction through mitigation; training for design professionals and governmental regulatory agency personnel that aims at improving their skills in applying mitigation concepts that may be recommended or mandated in standards and codes; and general public education that aims at advancing the understanding of earthquake risks by the public and their political representatives.

Concurrent with these education and training efforts, it would be helpful to have results from studies of public apathy with respect to earthquake risk--their perceptions, misperceptions, and views--in order to determine whether or not public education is even warranted and, if so, the form it should take to be most effective.

THE NATURE OF THE EARTHQUAKE THREAT IN ST. LOUIS

OTTO W. NUTTLI

Earthquake hazard in the St. Louis area arises from two causes: nearby earthquakes that produce short-duration, high-frequency ground motion and more distant earthquakes that produce relatively long-duration, low-frequency ground motion.

Figure 1 shows my version of the earthquake source zones of the central United States together with my estimates of the surface-wave magnitude of the earthquake with a 1,000-year recurrence time. The source zones closest to the St. Louis area are the St. Francois Mountain uplift to the southwest and the Illinois Basin to the east. The more distant zones are the Wabash Valley fault zone to the southeast and the New Madrid fault zone to the south. On average, St. Louis is 150 to 200 km form the Wabash Valley Zone and 175 to 350 km from the New Madrid Zone.

All four sources zones have produced earthquakes that caused damage in St. Louis. An M_s = 4.4 earthquake in April 1917, which occurred in the St. Francois uplift region about 60 km south of St. Louis, caused modified Mercalli intensity (MMI) V-VI effects in the city. This resulted in bricks being shaken from chimneys, broken windows, cracked plaster, and horses thrown to the pavement.

Two damaging Illinois Basin earthquakes occurred near Centralia, Illinois, about 100 km east of St. Louis. The June 1838 event was of M_s = 5.8 and the October 1857 event of M_s = 5.3. Contemporary newspaper accounts and some current earthquake catalogs mistakenly put their epicenters at St. Louis because of the amount of damage that occurred in the city. The former event caused a number of chimneys to be thrown down in St. Louis, corresponding to a MMI of VII. The latter produced only fallen plaster and cracks in walls and chimneys in the St. Louis metropolitan area, corresponding to a MMI of VI.

A M_s = 5.2 earthquake originated in the Wabash Valley region about 150 km from St. Louis in November 1968. In St. Louis the MMI was only V (cracked plaster, objects thrown off shelves, etc.) but in the eastern part of the metropolitan area the MMI was at least VI (cracks in walls and chimneys and people thrown to ground).

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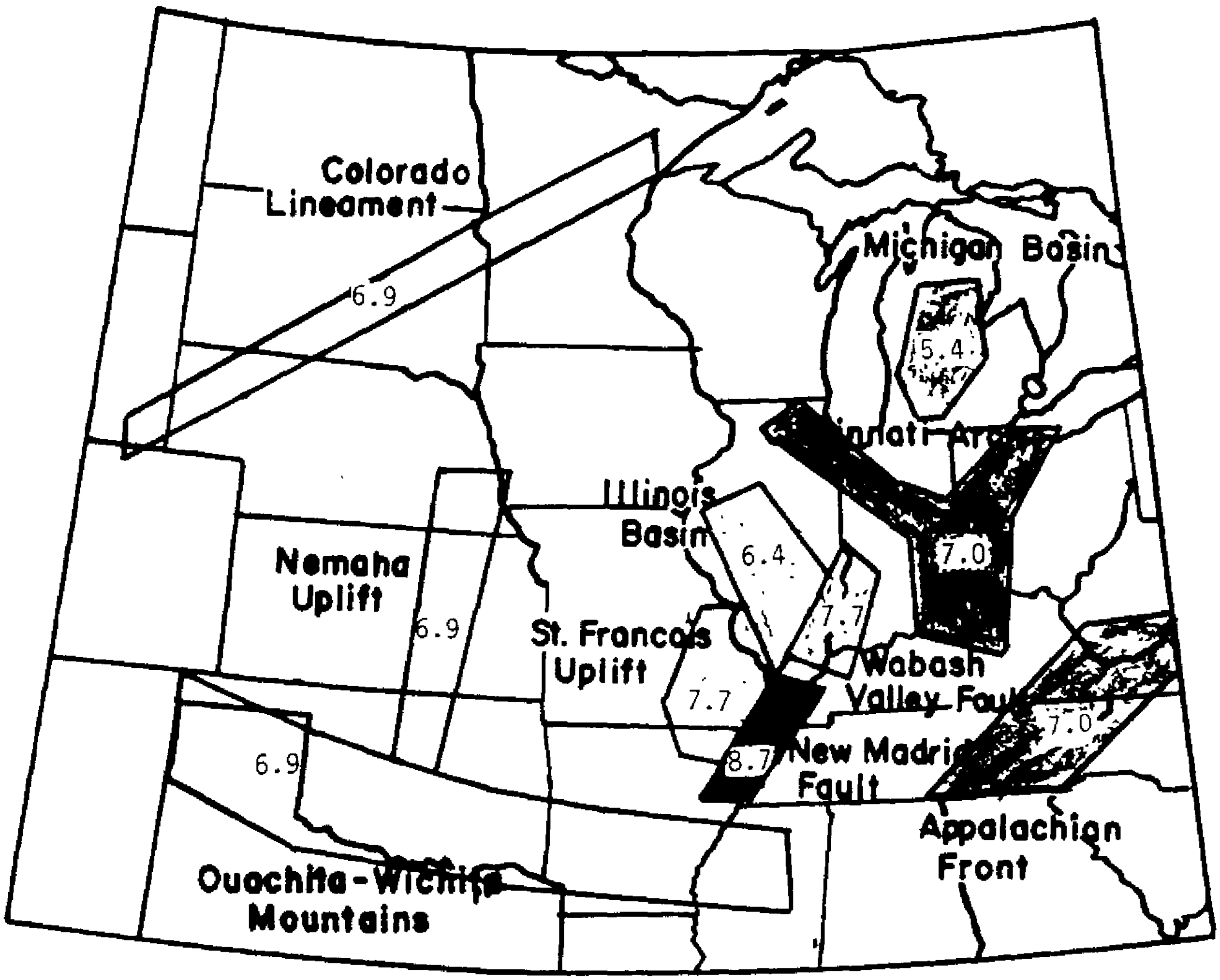

FIGURE 1 Earthquake source zones of the central United States.

The largest earthquake shaking in the St. Louis area since the city's founding in 1764 was caused by earthquakes of the New Madrid fault zone. Earthquakes in December 1811 and January and February of 1812 (M_S values ranging from 8.0 to 8.7) caused chimneys to be thrown down in St. Louis and 2-foot thick stone building foundations to be badly cracked. There were reports of sand catering and soil liquefaction in Cahokia, Illinois, just across river from St. Louis. The four largest earthquakes caused MMIs of VII to IX in St. Louis area. The October 1895 earthquake (M_S about 6.5) occurred near the northern end of the New Madrid fault and caused MMI VI effects at St. Louis. A few chimneys and old building walls were thrown down, suspended objects were thrown from walls, and groceries and other objects were thrown off shelves.

Future earthquake damage in St. Louis can be expected to be more severe than the damage produced by the past earthquakes. In the nineteenth century the population density was low and there were no high-rise structures. There were only 2,000 people living in the metropolitan area in 1811 as opposed to 2,400,000 today. Previously there were no pipelines, bridges, dams, or manufacturing plants with toxic substances to be affected. Futhermore, there was no great dependence on electricity, telephones, highways, and airports, and the economic impact of the disruption of such facilities must be considered.

It is not now possible to make short-term predictions of earthquakes in the Mississippi Valley: however, our knowledge of the earthquake history and the source physics of the New Madrid region permit some generalizations. During the next 50 years MMI VII motion can reasonably be expected in the St. Louis area from earthquake in the St. Francois uplift, the Illinois Basin, or the Wabash Valley region. The shaking will be of relatively short duration (30 seconds or less) and can be expected to cause widespread damage to the walls and chimneys of low-rise structures.

According to my calculations, the maximum earthquake that the New Madrid fault is capable of generating in the near future is one of $M_S = 7.6$. Figure 2 shows the MMI curves for such an earthquake if it were to occur on the central part of fault. The motion at St. Louis again would be of about MMI of VII, but it would be of relatively low frequency (about 5 to 0.1 Hz), of possibly 2 or more minutes duration, and sinusoidal in character. It would not cause structural damage to well designed, high-rise structures, but it would cause large-amplitude displacements at the upper levels and much nonstructural damage (e.g., fallen ceiling panels and light fixtures, moved and overturned furniture, and fallen debris within and outside the buildings). Widespread chimney damage to low-rise structures also should be expected. Sensitive equipment, including computer facilities, could be put out of operation or damaged. The probability of such an $M_S = 7.6$ earthquake occurring on the New Madrid fault is about 25 percent in the next 50 years according to Professor Arch Johnston of Memphis State University. However, he finds the probability of occurrence during the next 50 years of the size of the 1895 event to be about 90 percent. The extent of damage of this smaller earthquake in the St. Louis area will depend upon whether it occurs near the northern end of the fault as it did in February 1812 and 1895, near the southern end of the fault as in December 1811 and 1843, or in the central portion as in January 1812.

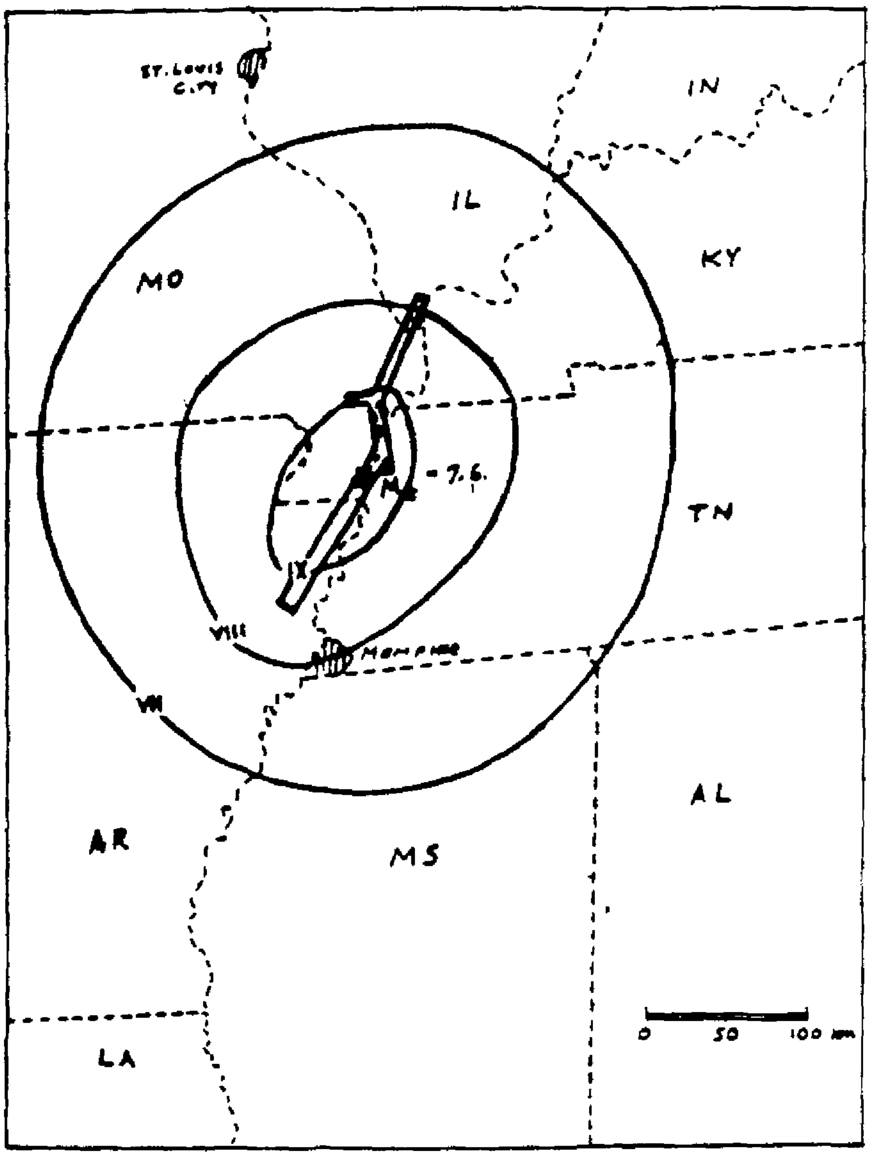

FIGURE 2 MMI curves for earthquakes generated in the New Madrid fault.

THE PURPOSE AND EFFECTS OF EARTHQUAKE CODES

THEODORE C. ZSUTTY AND HARESH C. SHAH

Abstract

When large earthquakes occur and there is significant damage and destruction of building structures, an almost universal response is the demand for better (and usually bigger) building codes. This paper examines the effects of this public outcry for protection with respect to the economic consequences, the actual process of seismic code formulation, and the technical adequacy of our present knowledge and design procedures. Some general directions are suggested such that new codes can be: better understood with respect to their intended design objectives; economically feasible; and practically enforceable.

The Purpose and Effects of Earthquake Codes

Earthquake codes are legally enforceable rules for the design and construction of new buildings and for the rehabilitation of existing older structures. These rules are intended to provide two basic objectives.

(1) An acceptable degree of protection against injury and property damage due to the effects of the moderate earthquake which may be expected to occur during the economic life of a structure.

(2) An acceptable assurance that lives are protected and structural collapse is prevented under the effects of a large catastrophic earthquake which might possibly (although quite improbably) occur during the structure life.

A most essential requirement of these rules is that they be applicable to all construction, such that the entire public is protected. The rules must have this quality of universal applicability if future disasters are to be avoided.

It should be recognized that some risk must always be accepted since earthquakes are future random events; and for every historical earthquake that has occurred, there may be a bigger one coming. The objective is to reduce the chance of damage or injury due to earthquakes down to the acceptable risks that we encounter during the course of normal life.

However, while the technology of earthquake engineering is reasonably adequate to provide these objectives of public protection, there are social and economic factors which in various ways have impeded the formulation of effective codes and their universal application to construction. The preventive factors include

- Time and effort necessary to formulate

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the basic code provisions. In order to understand this limitation factor, it must be appreciated that code provisions are formulated by committees of professional engineering groups, and not by any paid governmental agency or industry. The work is done individually or in committee during evenings or weekends as a volunteered effort by the most prominent professional engineers.

- Time and effort necessary to have the code provisions approved by the various technical committees and governmental agencies.
- Time and effort necessary to educate the engineers, architects, and constructors for the proper application of the new provisions.
- Time and effort necessary to provide a universal enforcement of the new provisions to all construction.

Also, in the recent past, in Caracas, Venezuela: San Fernando, California, and in Managua, Nicaragua, two extreme code situations have been common:

(1) Before the strong disastrous earthquake occurred in these population centers, codes were incomplete, nonappropriate for the possible intensity of seismic ground motion, and nonappropriate for the types of buildings and construction methods of the region, and possibly only partially applied and enforced. In this pre-earthquake case, new construction was certainly not impeded, and older structures were not bothered by rehabilitation costs; however, the public protection element was certainly lacking. Unfortunately, each large earthquake has very well searched out the deficiencies necessary for structural damage and failures.

(2) After the strong earthquake, emergency types of codes were formulated in order to satisfy very strong demands by the public for protection. *Unfortunately, these emergency provisions were so overconservative, and of such a degree of complexity that urgently required new construction was, and apparently still is, severely impeded.* For example, in California, new hospital construction has been significantly affected by the three to four multiples of earthquake design loads following the 1971 San Fernando earthquake. In the earthquake-devastated regions of Nicaragua and Guatemala where hospitals, housing, and commercial buildings are so critically essential, it is most urgent that a strong effort be made to create an effective code which cannot only provide universal protection but also meet the real requirements of design feasibility and construction economy.

It is the purpose of this paper to define the essential features of a workable seismic code and to give a history of various seismic code attempts such that past mistakes and failures need not be repeated. This will not be a criticism of the past attempts of very concerned officials who have done their best to rectify the chaos which follows destructive earthquakes, rather it will be an analysis of past behavior to improve the future. The topics to be discussed are:

- Relation of engineering design load to the quality and configuration of a building.
- History of past earthquake-resistant design load criteria and performance of modern construction.
- Public and political reaction to earthquake disasters in the form of emergency codes.
- Essential elements for a universally effective code are:

  —simplicity and economical feasibility,

  —distinct definition of the sites, structures, materials and occupancies for which the simplified code procedures are applicable, and

  —distinct definition of sites, structures, materials and occupancies where more refined methods are required.

Engineers must know the limitations of the necessary simplified assumptions and methodologies of the code. They must know when the uniqueness, complexity, or importance of a structure requires special studies, analyses, and design methods beyond those of the code

The Relation of Design Loads and Quality of Structure

Engineers model the effects of strong earthquakes as an application of lateral forces on a building. These represent the inertial loads as the structure is accelerated from side to side during the earthquake. The phenomenon may be visualized as the push of a giant hand on the side of a building. The results of this "push" are a sidewise bending or drift of the structure, and intensified forces, moments, and shears in the columns, beams, and walls of the buildings (see Figure 1).

The occurrence of a strong earthquake may cause drift values of such magnitude that windows, interior walls, elevators, and service ducts are seriously damaged; therefore, the control of this drift by means of frame rigidity, stiffening braces, or walls is a most essential engineering objective. Further, the individual structural elements must be both strong and tough enough such that columns do not buckle and collapse (Figure 2), beams do not fracture in flexure or shear (Figure 3), and walls do not shear apart or overturn (Figure 4). It is most important to realize that an earthquake can have widely differing effects on different types of buildings, depending upon their qualities of symmetry and regularity (as shown in Figure 5).

If a building is well braced by walls, regular and symmetrical, drift is easily controlled. If, however, there are drastic irregularities from floor to floor, or if the plan is grossly nonsymmetrical in its floor plan or with walls on one side and flexible framing on the other, then severe localized drift and torsional twisting distortions will occur.

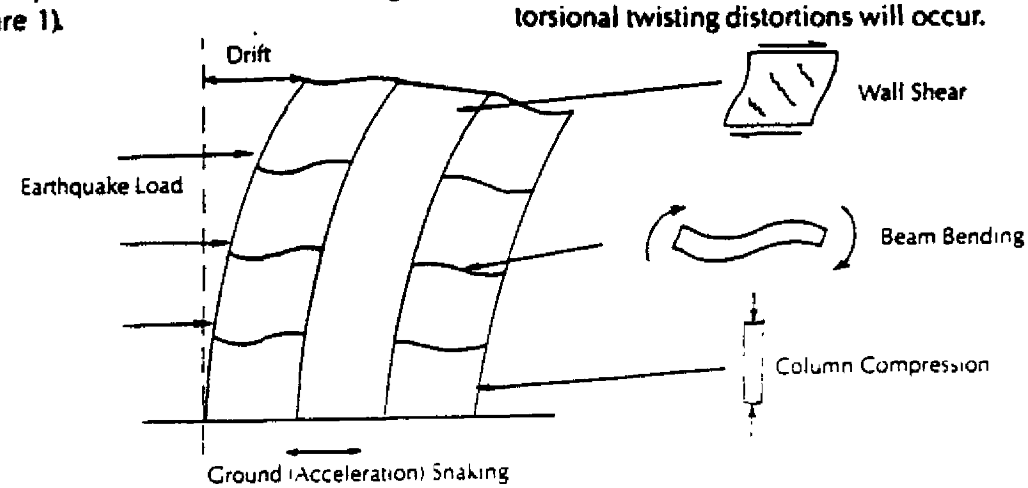

Figure 1. Earthquake Load Effects

Figure 2. Column Failure

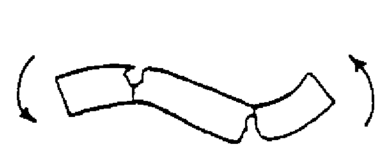

Figure 3. Beam Failure

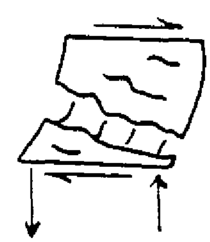

Figure 4. Wall Failure

Further, if the members are strong and tough, then the shaking punishment of the earthquake can be absorbed. If the members are brittle due to poor materials, careless design and construction, or if the connections of the walls, floors, and frame are weak, then only very moderate earthquakes can create damage and collapse. Also, it is important to recognize the existence of the very fragile category of structures consisting of old buildings, primarily masonry and decayed wood or brittle concrete. These buildings, which usually house the largest number of occupants, have waited long for their trial by earthquake, and they are too feeble to put up a fight without serious damage or collapse. Methods for their strengthening and rehabilitation is an essential element of a code.

Bearing all of these building qualities in mind, engineers employ design loads (the representation of the side push of the earthquake) as the means of proportioning the strength or size of the beams, columns, and walls of a building. If a structure is regular, symmetrical, and possesses tough and well-constructed elements, then it has natural qualities of earthquake drift control and energy absorption. The design loads for this structure can be set at a relatively low level without endangering the earthquake-resistant capabilities. On the other hand, if there are irregularities in configuration or inherent brittleness in the construction, then these weaknesses must be compensated for by large design loads with their resulting large member sizes. This is necessary in order to provide the same earthquake resistance as the regular tough structure with its low design loads. From the economic standpoint, large design loads mean large material and construction costs, and low design loads, therefore, have a distinct cost advantage, provided that the proposed structure can qualify for these low loads.

However, while the concepts that have been explained in the preceding paragraphs are well understood and accepted by the engineers in the field of earthquake-resistant design, the general public and governmental

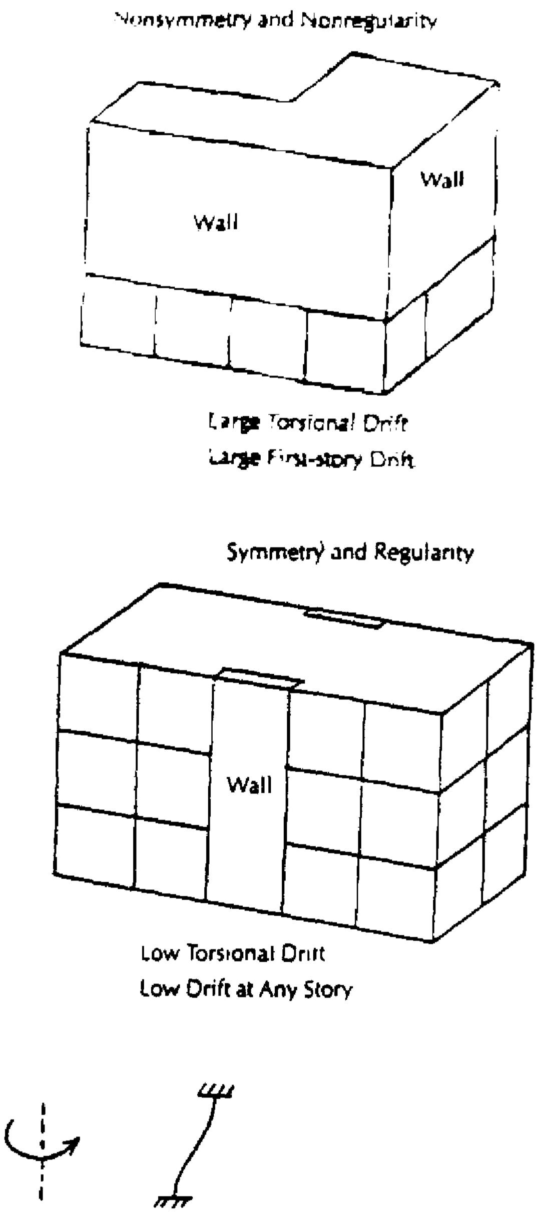

Figure 5. Building Configurations and Behavior

officials look more on the general destructive results of an earthquake, and their desires are to avoid this destruction. Therefore, the next topics required for understanding the problems in the generation of earthquake codes are: the review of the history of seismic load criteria, and the effects of public reaction after a strong earthquake.

History of Earthquake Loading Criteria

In the 1930s to the 1950s, the structural engineers of California (with recognition of the experiences of Japanese engineers) generated the basic earthquake code and design procedures which are employed throughout the world today. It is most important to several specialty areas:

- Site Exploration: the research of all available geological information and the physical trenching and exploration necessary to detect active earthquake faults or any other sources of hazards such as landslides or settlement.
- Site Response Analysis: the research of all available geological and seismological information necessary to predict future earthquake motion at the bedrock level under the structure site. Soil exploration and drilling is then performed to determine the dynamic properties of the soil layers between the bedrock and the structure. A mathematical model of the soil layers is formulated and computer analyses are performed to predict the surface response of the earthquake motions at the bedrock level. These calculated surface motions are then employed for the design of the structure.
- Advanced Dynamic Response Analysis: given either past earthquake records or the results of the site response analysis, a step-by-step computer analysis provides a complete record of the seismic response of proposed building design. Engineers employ the results to verify the design strength and drift control of the structure.

Again, these are all valid areas of investigation and analysis and it is definitely not intended here to say that the work in these areas is not necessary: the outlined operations are essential for important and unusual structures and for special site conditions, but good judgment is required in the definition of criteria before they are made to apply to general classes of ordinary buildings with regular configurations and standard structural systems. Recent past experience in California and in Nicaragua has been that when legislation requires that very conservative versions of these operations be applied for large classes of essential facilities such as schools and hospitals, *then more public harm sometimes results from the delay and extra costs than from any probable earthquake effects.* A school should not be moved or delayed in construction because it exists near a small fault which has not shown activity in the last 10,000 years. A hospital or medical facility or convalescent home should not have drastic increases in construction cost and, therefore, should not be built because of a mathematical site response analysis that triples the earthquake design load values that have been used for presently existing hospitals. Also, substantial delays which increase contract bids, should not be caused by unnecessarily long plan check procedures for these health facilities.

In the review of the effects of recent past earthquakes, no building failures have been due uniquely to the absence of knowledge that would have been provided by the above listed specialty investigations and analyses, other than perhaps risk zoning for the appropriate design load levels based on the seismicity of a region and general soil conditions at the site. Practically all of the past failures would not have occurred if the building design had conformed to the letter and intent of the 1973 (and even more definitely by the 1979) Uniform Building Code. This is to say that good codes now exist to provide appropriate load levels and methods of design for given building types and materials.

Therefore, future code development work does not require inclusion of more refined analyses of seismicity, site response, or building response for most buildings (i.e., ordinary structures), but rather it involves a clarification of the cases where special procedures are required. In short, there must be an educational process that will allow all designers of buildings to understand the intent of our most current codes and to understand the way in which a properly designed building resists drift damage effects during a moderate earthquake and provides against collapse during a catastrophic earthquake. The present code load levels and methods of design are reasonably sufficient for most buildings, *but the present code does lack the element of rationality* along with a clear definition of the conditions where special investigations are required. With these weaknesses, it is easy for inexperienced designers to misinterpret the provisions of the code and thereby create unsafe structures. It is, therefore, quite necessary to rewrite the format of the code so as to properly define appropriate design force levels for the various types and configurations of structures, and to provide a rational relationship of each design step to the actual earthquake response.

Essential Elements for an Effective Code

The basic elements of this rational code format are as follows:

- Seismic Risk Zoning: such that earthquake design loads depend on the acceptable risk of the occurrence of earthquake ground motion during the structure life at a given location.
- Importance Factors or Drift Control Provisions: such that important facilities are designed to have a lesser risk of seismic damage.
- Site Factors: such that probable significant soil response effects are represented in the design load.
- Structure Type Factors: such that design loads are dependent upon the stability, toughness, and reliability of a given structure configuration and its material components and construction details.
- Drift Control: such that moderate earthquakes will not cause damage, and catastrophic earthquakes will not cause collapse.
- Member Design Rules: such that the individual structure components and their connections can provide the toughness required to fulfill the objectives of damage control and collapse prevention.
- Definition of the special structures and conditions which would require a more detailed analysis.

Each of these elements should have a descriptive commentary complete with illustrative examples such that all engineers can properly understand and apply the methods and responsible construction agencies can enforce them.

The knowledge is now available and a concentrated and organized effort by the engineering community is required for the creation of this code. In summary, a good "rational" code should make every designer aware of the following concepts and procedures:

(1) At the site where the structure is to be located, there can occur two important levels of earthquake ground motions
   (a) a moderate earthquake for which damage must be controlled and
   (b) a major or catastrophic earthquake for which collapse must be prevented. A zone map should furnish the design load information representing these two earthquakes, each having their own acceptable risks of occurrence at the site of the structure.

(2) An analysis procedure should be defined which predicts the forces and deformations of the moderate earthquake and the deformations of the

major earthquake on the proposed building structure. This should include methods of predicting the seismic behavior of nonsymmetrical or nonregular structures.

(3) Rules should be given that identify the earthquake design loads appropriate for the given building properties of
  (a) earthquake-force resisting system
  (b) building configuration
  (c) structural back-up systems and redundancies
  (d) type of materials
  (e) type of member design and their connections
  (f) quality of analysis
  (g) quality of construction
  (h) quality of supervision

(4) Structural and nonstructural damage control should be verified at the design load and deformations of the moderate earthquake.

(5) Structural stability and collapse prevention should be verified at the deformations of the major earthquake.

(6) There should be proper definition of the building plans and specifications and enforcement such that the as-built structure conforms to the design. ■

SUMMARY OF RECENT RESEARCH

ON LOCAL PUBLIC POLICY AND SEISMIC SAFETY MITIGATION

CLAIRE B. RUBIN

A number of social scientists have studied local seismic safety policy and development and implementation in California (Nilson and Nilson, 1981; Wyner, 1984; and Wyner and Mann, 1983). Their work has focused mainly on key actors (public and private) rather than on the general public. Recently, some experienced researchers have begun to do similar work in the central states (Drabek et al., 1983; Nigg and Mushkatel, 1984). In their studies of seismic safety policy in the central United States, their work has brought them into contact with both key actors and the general public. In addition, they have covered a relatively broad spectrum of seismic safety issues (i.e., new construction, retrofit construction, and other mitigation actions). Nigg and Mushkatel are still engaged in related research and additional reports on their work can be expected.

Differences in findings regarding the leadership role of the key actors and the general public is reflected in the work of these researchers. There is no question that the effort entailed in convincing municipal officials in most seismic zones in the United States to adopt and implement seismic safety regulations (and related mitigation measures) is sizeable. Nevertheless, a not-yet-completed Nigg and Mushkatel study, the Central States Seismic Safety Study, may foster a more optimistic view of the likelihood of accomplishing seismic safety policy adoption and implementation in the central and eastern United States than was thought to be the case.

Researchers Douglas and Linda Nilson (1981) have examined seismic safety planning strategies in California and extracted lessons from them for Easterners. They note that although California is a leader in seismic safety planning, other earthquake-prone areas should discriminate in what policies and activities they "borrow" from California. They caution Easterners to examine both the effectiveness and the appropriateness of each seismic safety policy being considered. Overall, in states other than California, they characterize the seismic safety situation as "one of low visibility and, hence, low preparedness." They also note that the "attitudinal and preparedness environments in other regions must be contrasted with the more earthquake aware...environment of California."

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The Nilsons have drawn several conclusions regarding California and developed several recommendations for Easterners on the basis of those conclusions. Briefly stated, the Nilsons California conclusions are as follows:

1. The public accepts government regulation of "future" building and development as being much more legitimate than "retrofit legislation."

2. If public officials can show that there is a clear and unambiguous life safety threat from already existing buildings or land use patterns, public opinion may support reasonable retroactive legislation.

3. Seismic safety proponents must be sensitive to the fact that political processes, even at the local level, are highly differentiated.

4. Sincere and rigorous implementation of seismic safety measures is a particular problem for public officials when a program's initial supporters have lost interest in it but an "attentive public" long opposed to a program's measures remains very interested.

5. The public can be motivated to support a wide range of seismic safety policy but only through a coherent program with defined objectives and a thorough understanding of public opinion formation.

6. Members of the "elite" can also be motivated to support seismic safety but the best education strategy to use for them is to "link" earthquake hazard mitigation and preparedness measures to other important social goals.

Among the Nilsons (1981) recommendations most pertinent to communities east of the Rockies with some degree of seismic risk are the following:

1. In the eastern and central United States, initial building regulations should be limited to controlling new construction of schools, hospitals, and critical facilities. Only after those controls are firmly established should the regulation of new industrial, commercial, lifeline, and housing construction be considered.

2. The second wave of policy should concentrate on retrofitting existing schools, hospitals, critical facilities, public buildings, and (ultimately) high-occupancy, privately-owned hazardous structures.

3. Scientific and engineering specialists should work "behind the scenes" to negotiate agreements stating that all new public and utility construction will meet stringent code requirements.

4. In the absence of a "stimulating" earthquake, land use measures should remain a tertiary line of policy and be limited to underdeveloped areas close to defined faults.

5. Publishers and broadcasters within modified Mercalli intensity VII isoseismal belts in the eastern and central states should be persuaded to devote space or time to publicizing the earthquake danger.

6. A general public education campaign should be supplemented by more sophisticated campaigns aimed at elites.

7. Federal officials should promote and financially support at least one interstate seismic safety commission.

Another researcher, Alan J. Wyner (1984), has written about public policy implementation experiences in 13 California communities. He has commented that seismic safety policies are almost always problematic and that they may be more susceptible to implementation problems than other public policies. Based on his empirical studies, Wyner has cited the most important aspects of seismic safety policy implementation in California as being: (1) the role of key governmental personnel, (2) the political environment surrounding the issue of seismic safety, and (3) the tractability of the issue itself. He notes that:

> Given the way these three aspects interact, and because seismic safety is not an issue that generates consistent expressions of organized public support, policy implementation will always falter unless a highly committed and motivated core of public officials diligently pursue implementation.

Underscoring the important role of key government personnel is the fact that in the seismic safety policy area, nongovernmental interests are not usually pressing local government for action. Wyner (1984) notes that: "What policy that is implemented--and the degree of its implementation--will be determined in spite of and not as a result of public expressions of organized local interests groups."

Regarding the political environment, Wyner identifies three aspects of interest: organized interest group support, mass public support, and the political benefits or incentives for officeholders. He states: "Seismic safety is not an issue that has stimulated the creation of new interest groups, nor, for the most part, has it been an issue that has attracted the support of already established interest groups."

Wyner (1984) notes that the benefits of adopting and implementing seismic safety regulations are not easily discerned and he concludes that: "Successful implementation of seismic safety policy cannot be simply assumed. Rather, the norm may be delay and less than full accomplishment of the policy goals envisioned when the policy was adopted." In other words, it is essential to remember that seismic policy implementation efforts do not just happen because a law was passed.

Wyner (1984) further observes that:

> Implementation of seismic safety regulatory policies in the area of land use and building code enforcement creates costs borne by a specific target group, such as the building owner or land developer. The benefits, however, are spread in a diffuse manner to all those individuals, for example, who may happen to be in or around a building that would otherwise collapse in an earthquake absent successful implementation of seismic safety...a case of "distributed benefits and concentrated costs."

Joanne Nigg and Alvin Mushkatel (1984) are studying seismic hazard perception and policy development in the central United States, an area that has had relatively little damaging seismic activity in the recent past. According to Nigg and Mushkatel (1984), their study reveals some important findings with respect to the relationship between key actors'[1] and the public's attitudes:

> First, the public's level of concern about a future damaging earthquake striking their community is higher than that of key actors regardless of the attitude indicator used.... More importantly, there is far more support for both structural and nonstructural mitigation measures among the public than among key actors. The increase in support for these mitigation measures is more than 50 percent higher for citizens than for key actors. ...there is a stunning lack of commonality between key actors' and the public's view concerning earthquake threat and mitigation practices, but the difference is not in the direction that previous research would lead us to expect. Instead, it is the public which is supportive and the key actors who fail to see the value of seismic mitigation policies.

These findings differ from those of other researchers who interviewed only key actors (Drabek et al., 1983; Wyner, 1984; and Wyner and Mann, 1983). Drabek and his co-workers (1983) found "high levels of salience among key actors in Missouri for seismic issues as well as strong support for the formulation of mitigation policy." Yet, they also learned that the perception of the key actors regarding citizen awareness was very low and that the "key actors felt that the citizens in Missouri were unaware of any seismic threat to their community." Wyner and Mann (1983), after studying seismic safety policy development in cities in California, reported that the key actors they interviewed indicated that the "public's concern over seismic safety was minimal."

They suggested this low concern was due to the belief that although

[1]Nigg and Mushkatel use the term "key actors" to mean "those individuals who hold elective or functional positions in some way related to preparing for or mitigating or responding to an earthquake." They were concerned primarily with key actors at the local (city and county) level of government but also included a sample of state legislators representing the cities studied.

there was a high level of public awareness of the seismic risk, the public also felt that little could be done to reduce the risk or to alter the consequence of a major earthquake.

In short, the earlier studies found the strong belief among key actors that the public is either unaware of seismic mitigation issues or unwilling to support the formulation of such policies because of fatalism or economic costs to the community. Nigg and Mushkatel, however, found "a stunning lack of commonality" between the perceptions of the public and those of local public officials concerning the earthquake threat and mitigation practices in their community with the surprising outcome that "it is the public which is supportive and the key actors who fail to see the value of seismic mitigation policies." It will be interesting to see the final results of their study.

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