Kates, R. W., 1970. "Human Adjustment to Earthquake Hazard", The Great Alaska Earthquake of 1964: Human Ecology, National Academy of Sciences-National Research Council Publication No. 1607, pp. 7-31.

ROBERT W. KATES
CLARK UNIVERSITY

Reprinted from
The Great Alaska Earthquake of 1964: Human Ecology
SBN 309-01607-X
NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1970

Human Adjustment to Earthquake Hazard

ABSTRACT: Theoretically, human adjustments to earthquake hazard are those that attempt to alter the earthquake mechanism, to modify the hazard or the loss potential of human occupance, and to bear the losses when they occur. In Alaska before the earthquake such adjustments were indeed modest. Previous loss of life and property damage were low, minimal amounts of earthquake and fire insurance were in force, earthquake warning measures and provision for disasters were rudimentary, and the tsunami warning system, while more elaborate, was least effective for locally generated tsunamis. Seismic requirements in building codes were in force in three cities, but supervision and care in construction and detailing was of mixed quality.

This low level of adjustment influenced the pattern of loss occurrence and loss bearing. Nevertheless, in view of the magnitude, extent, and duration of the geophysical event, the relatively small loss of life and property damage were remarkable. A significant impact of the earthquake is its service as a warning of potential future damage, particularly in California. Applying the low rates of Alaskan death and damage to all of Seismic Zone 3 gives a prospect of a 100-year toll of 11,000 dead and $24 billion in property losses. The adoption of a comprehensive national program for earthquake loss reduction might reduce death by about 70 percent and property loss by 50 percent, still leaving a large catastrophic potential for the future.

INTRODUCTION

Most of the human race take the stability of the earth for granted. Even those trained to recognize the dynamic nature of the lithosphere seldom consider how cycles of human life and death are related to the geologic times involved in cumulative dislocations of the earth's crust. Human adjustment to earthquake hazard thus requires adaptation to phenomena that confuse man's senses and confound his beliefs.

However, these perceptions of the world are not sufficient to account for man's widespread failure to design and implement strategies that would reduce damage and loss of life from earthquakes. The ambivalence of human response is compounded by two characteristics of earthquakes: the release without warning of prodigious amounts of energy, and the infrequent occurrence of earthquakes at any one point, even in areas of high seismic activity. A further complication is the paucity of knowledge about earthquakes: we do not know their causes, we have no way to predict them, and we lack adequate statistical information for estimating the probability of their occurrence at a specific site. In this country the general lack of concern about earthquake hazard stems from our experience with earthquakes, which so far has been remarkably fortunate. Only three seismic events in this century (San Francisco, 1906; Hawaiian tsunami, 1946; Alaska, 1964) have been marked by substantial loss of life, much of which resulted from tsunamis. Thus the motivation for preparing for earthquake-associated disaster has been absent during much of the period in which national policies for other natural hazards have been fashioned. The Alaska earthquake of 1964, however, and the concern that it engendered provided just such motivation for this review. Through a format developed in studies of other natural hazards—floods, storms, and droughts—this paper seeks to evaluate the Alaska earthquake experience and its implications as part of an overall review of the human aspects of the earthquake problem.

THE COMPLEX NATURE OF EARTHQUAKE HAZARD

THE CAUSES OF EARTHQUAKES

Quite simply, "we do not know the cause (or causes) of earthquakes." The Ad Hoc Panel on Earthquake Prediction (1965, p. 3) summarizes our ignorance of earthquake mechanisms:

> A classical view of the earthquake mechanism postulates a building up of stresses from unspecified sources until some limit is reached and fracture occurs. This hypothesis accounts for the slip, the strain-energy release, and the radiation field of seismic waves. However, the overburden pressure at a depth of only a few kilometers in the earth is sufficient to suppress brittle fracture of dry rock. The stress drop of 100 bars (1 bar is approximately 1 atmosphere) observed for a major earthquake is at least an order of a magnitude less than the strength of the rock or the frictional forces which lock the faces of a fault. Although high temperature promotes inelastic deformation in the laboratory, catastrophic failure is not observed under confining pressure. Suggestions for resolving this dilemma have been advanced, but their pertinence to earthquakes has yet to be established.

The Panel does note that "it is possible that some degree of earthquake forecasting can be achieved with imperfect understanding of the physical mechanism (the prediction of weather, tides and volcanic eruptions, are examples)" (p. 5). Almost all other forms of geophysical hazard, however, are accompanied by related surface phenomena that assist in prediction or have frequency distributions of occurrence that are fairly well defined. Without these additional indicators, ignorance of the physical nature of earthquake mechanisms accentuates the uncertainty under which human adjustment to earthquake hazard must take place.

EARTHQUAKE HAZARD

It is convenient to distinguish three aspects of earthquakes from one another: (1) *earthquake mechanisms,* the processes related to fracture of the earth's crust, (2) *earthquake hazard,* the physical manifestations of the event at the earth's surface, which are potentially harmful to man, and (3) *earthquake damage,* the actual harmful effects of earthquakes on man. These relationships are shown in Figure 1, where man and his works (settlements, cultural features, activities, and the like) are subsumed under the term *human occupance.*

A simple classification of hazard is used to distinguish between the direct surface manifestations of the earthquake–ground motion from seismic waves or tectonic

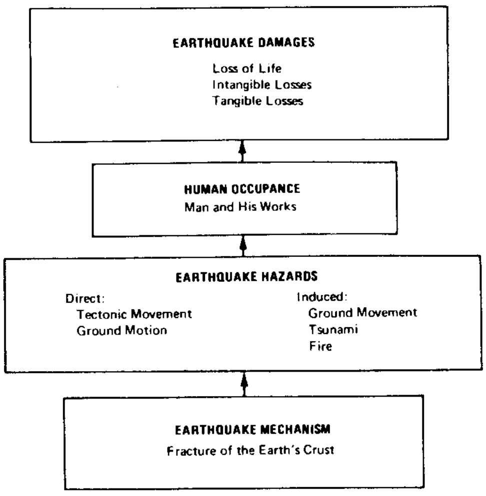

FIGURE 1 Earthquake mechanisms, hazard, and damage.

movements of the surface–and what might be called the induced effects of the earthquake–the secondary ground movements that were induced by ground motion: subsidence, compaction, landslide, and soil failure. Other induced effects include the propagation of local waves and tsunamis (seismic sea waves), and the naturally initiated but artificially propagated earthquake fire hazard. The variety of hazards makes the devising of strategies for damage reduction more difficult. For example, low-mass wooden structures provide optimal resistance to ground motion but present a great fire hazard. Nevertheless, it is possible to distinguish in theory a wide range of potential adjustments to earthquake hazard in all its varied forms. The following model of alternative actions is a construct through which to view the Alaskans' adjustment to seismic hazard, both before and after the great earthquake of 1964.

POTENTIAL ADJUSTMENT TO EARTHQUAKE HAZARD: THE RANGE OF ALTERNATIVE ACTIONS

In general, men may seek to adjust to damages by planning for them, and bearing or sharing them when they occur; they may attempt to reduce the potential for loss by organizing human occupance so as to minimize damage; they may seek to minimize the hazard by careful site selection, placement of sea-wave barriers, or the provision of earthquake-resistant fire protection; and finally, in ways only to be speculated on, they may seek to affect the actual earthquake mechanism. These groups of actions, shown schematically in Figure 2, require some discussion.

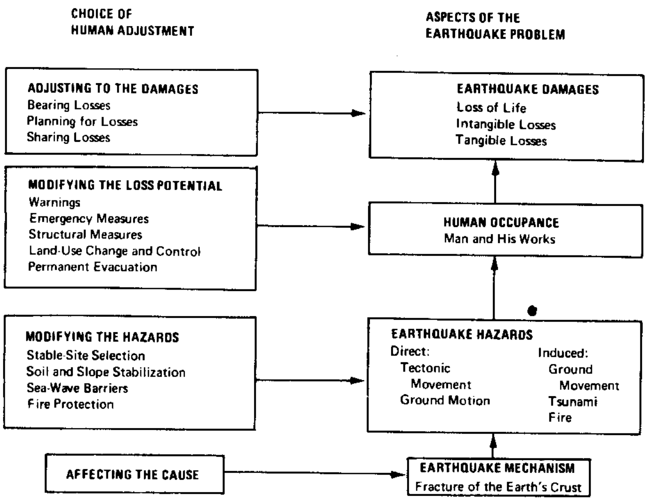

FIGURE 2 Potential human adjustment to earthquakes.

ADJUSTING TO DAMAGES

Bearing Losses

The most common human response to all natural hazards is to bear the losses when they occur. It is important, however, to distinguish between the expected and the unexpected. Consider well-informed individuals or groups that locate in areas of potential seismic activity. If they share in professional knowledge relevant to the hazard, bearing a loss when it occurs can be considered either as a kind of gambling with nature, a form of self-insurance, or as simply the payment to nature of a rent that is sporadically collected. In any event, except where there is a high risk of loss of life, or where the property or persons of other individuals becomes imperiled, our tradition of law and community views such actions as inherently rational.

The proportion of such well-informed groups in the population, however, is probably low. We know little about the perception of earthquake hazard among residents of seismically active areas. From the fact that earthquakes large enough to be felt but not large enough to cause serious damage are common in such areas (the expected ratio of felt earthquakes to damaging earthquakes is about 50:1, according to U.S. Environmental Science Services Administration, 1965, Table I/10), and from our knowledge of behavior in other hazardous areas, it would be safe to infer that total ignorance of potential earthquake hazard is very rare. It is equally rare to find residents who share both the knowledge and the misgivings of the professionals in the field of geologic hazard. The problem of whether earthquakes are really expected is further complicated by the historic occurrence of great earthquakes in areas not previously recognized as seismically active, a notable example of which is the Charleston, South Carolina, earthquake of 1886.

Whether an event is expected or unexpected, what is the probability of earthquake losses occurring? It is possible to state that the world can expect on the average one great earthquake every several years with a magnitude of 8 or larger. Maps are available on global and regional scales showing the occurrence of earthquakes (Gutenberg and Richter, 1954), earthquake histories of the United States have recently been published (Eppley, 1965, 1966), and some attempts, both in the United States and elsewhere, at seismic regionalization have been made (reviewed in Medvedev, 1965, p. 22–37). However, there is no uniform system for the collection of earthquake data in terms of their human impact, and the listings that are available are therefore highly selective. From scattered sources (including data compiled by Douglas Dacy, Institute for Defense Analyses), the average annual loss of life in the United States for a 20-year period (1945–64) was 3 deaths from earthquakes and 18 from tsunamis. Property damage for the same period averaged $15 million for earthquakes and $9 million for tsunamis (1967 dollars). From an obsolete map of seismic probability (the only one of its type available and which still serves as a basis for building-code seismic regionalization: Stepp, 1966, Figure 1) and unpublished maps of Alaska and Hawaii, we have calculated (with the assistance of N. West) that 7.8 percent of the land area of the United States, on which 20.0 million people resided in 1960, is in Seismic Zone 3 where major damage might be expected to occur in the future on the basis of past earthquake experience. An additional 27.1 percent of the land area of the United States, and 24.5 million residents, are included in Seismic Zone 2, an area that has experienced moderate but not catastrophic damage in the past.

Planning for Losses

An alternative to bearing losses when they occur is planning for them ahead of time by providing reserves or, more commonly, through some form of insurance. Earthquake insurance is available in seismically active areas, but its sale is not encouraged by commercial firms. Typical costs of this insurance seem high for all but frame buildings and generally require a deduction of 5–15 percent of building value before settlement is made. Only a very small portion of real property in seismically active areas is now insured.

An alternative to the American system of private voluntary earthquake insurance is the system used in New Zealand. There a small surcharge is placed on all fire and extended-coverage insurance and is collected by the private insurance companies. This sum goes into a central government fund, out of which are paid not only earthquake damages, but war, flood, and storm damages too. At present, a substantial fund has been built up because New Zealand has not experienced a catastrophic earthquake since the fund was started in 1941, and, in the absence of such a catastrophe, the insurance scheme seems to be functioning quite satisfactorily. Over the past 25 years, about $800,000 (U.S. dollars) has been paid out for earthquake claims (New Zealand Official Year Book, 1965).

Many variants on insurance schemes exist; they may be completely private, profitable, and self-sustaining, or they may be wholly governmental and tax-subsidized. In the United States, an example of a combined program is one for indemnifying victims of nuclear hazard, where industry operating nuclear electric-generating plants carries liability insurance of $60 million, and additional indemnification up to a statutory limit of $500 million is provided by the federal government (Public Law 256, 85th Congress). More recently, enactment of the National Flood Insurance Act of 1968 (Public Law 90-448, 90th Congress) provides for alternative patterns of federal-private flood insurance. The preferred program provides for an industry-created flood-insurance pool with federal assistance. But if this program proves unworkable, the act provides for a government program with the insurance industry serving only as fiscal agent. At this writing the feasibility of a similar proposal for earthquake insurance is under intensive study with a report to the Congress forthcoming.

Sharing Losses

The New Zealand insurance scheme or the nuclear-indemnification provisions of the Price-Anderson Bill and the Flood Insurance Act represent more than planning for or pooling losses, they involve sharing as well. In the New Zealand program, all citizens who carry any property-damage insurance at all are required to contribute to the program. In effect, all property, regardless of hazard, is taxed to minimize the risk of owners of particularly hazardous structures or locations. In the nuclear case, the Treasury of the United States, and indirectly the treasure of its citizenry, is pledged to provide for catastrophic losses. And in the case of flood insurance, specific provision is made for charging rates below the actual risk premiums to "encourage prospective insureds to purchase flood insurance" (82 Stat. 576), with the difference in premiums coming from a federal subsidy.

Policies of the Internal Revenue Service lead to still another form of loss-sharing. Because victims are allowed to deduct earthquake property losses, part of these losses are eventually shared by the tax-paying public.

The oldest form of loss-sharing known to man is charity. In its modern form, this method amounts to relief and disaster assistance during the emergency period and reconstruction assistance over a longer period. The familiar forms of assistance during the emergency period following an earthquake involve first, medical attention (if needed) and then the provision of food, shelter, and clothing, either through the creation of new facilities or through emergency actions to get existing facilities functioning again. To the extent that these necessities are provided free, some costs of disaster are thereby mitigated for the victims.

Sources of such aid are governmental (for example, surplus-property stockpiles), quasigovernmental (primarily the Red Cross), and private (The Salvation Army, church organizations, service clubs, and industry). For the mitigation of losses, aid in the form of reconstruction assistance is of much greater importance. The value of this total aid may be considerable, even exceeding tangible estimates of damage. The priority of reconstruction generally involves, first the restoration of "essential" services, then provision for housing, and then efforts to restore normal economic activity. In the United States, so many sources of such assistance exist that a major problem of coordination is created, and available assistance may be underutilized, either from ignorance or frustration. On the federal level alone, sources of disaster assistance involve 24 agencies. The most recent federal-assistance index is reproduced as Table 1.

International disaster assistance has been of little importance in the North American context but is the major form of disaster assistance for much of the world. The international colony of prefabricated housing at Skopje, Yugoslavia, bears witness to the importance for most nations of extranational assistance (Larrabee, 1964). In this way, their losses are shared with the world. In a 4-year period (1964–1968), the U.S. Government and American voluntary agencies contributed cash, goods, and transportation valued at $211 million in 215 foreign disasters including many earthquakes. Other countries and organizations provided an estimated additional $203 million (Kotschnig, 1968). Recently the United Nations has moved to seek a greater role in coordinating international disaster assistance, particularly in the reconstruction phase (United Nations Centre for Housing, Building and Planning, 1966).

One little-known aspect of the various forms of sharing losses (subsidized insurance, or the charitable efforts of relief and reconstruction) is their effect on the choice people make with respect to adjustment to earthquake hazard. Possessing insurance may militate against adopting other adjustments, much as having auto-theft insurance tends to make locking the car door seem less necessary. In like manner, the assurance that a society concerned with human welfare will try to protect its members from undue suffering shifts somewhat the burden of responsibility from the individual to the community.

TABLE 1 Federal Assistance Index

Problem or Service Desired	Agency to Consult
Communications	Federal Communications Commission
Conservation, farm	Agricultural Stabilization and Conservation
Contaminated food, drugs	Food and Drug Administration
Crop insurance	Federal Crop Insurance Corp.
Damage assessments	Office of Emergency Planning
Disaster plans	Office of Emergency Planning, Office of Civil Defense
Disease control	U.S. Public Health Service
Employment assistance	Department of Labor
Family and individual: food, clothing, shelter, household furnishing, repairs, and financial assistance	American National Red Cross
Executive reserve	Office of Emergency Planning
Federal agency coordination	Office of Emergency Planning
Feed grains, reduced prices	Agricultural Stabilization and Conservation
Flood fighting	U.S. Army Corps of Engineers
Flood protection	U.S. Army Corps of Engineers, Bureau of Reclamation
Free feed grains	Agricultural Stabilization and Conservation
Haying and grazing	Agricultural Stabilization and Conservation
Home-loan adjustments	Federal Housing Administration; Veterans Administration
Loans, community facilities	Community Facilities Administration
Loans, economic injury	Small Business Administration
Loans, farming operation	Farmers Home Administration
Loans, homes and businesses	Small Business Administration
Loans, rural housing	Farmers Home Administration
Locator service	Post Office Department; American National Red Cross
Mail service	Post Office Department
Manpower	Office of Economic Opportunity; Department of Labor
Maps	U.S. Coast and Geodetic Survey; U.S. Geological Survey
Medical care	U.S. Public Health Service; American National Red Cross
Military assistance	Department of Defense
Military coordination	Department of the Army
Repairs, federal-aid roads	Bureau of Public Roads
Reduced transportation rates	Interstate Commerce Commission
Rehabilitation, vocational	Vocational Rehabilitation Administration
Repairs, public facilities: roads, bridges, sewer and water systems, public buildings and facilities	Office of Emergency Planning
Repairs: shore and hurricane protective works	U.S. Army Corps of Engineers
Repairs: roads, streets, and bridges	Office of Emergency Planning
Sanitation	U.S. Public Health Service
Schools, maintenance and operation	Office of Education
Schools, repair	Office of Education
Search and rescue	U.S. Coast Guard
Social Security benefits	Social Security Administration
Soil restoration	Soil Conservation Service
Stockpile civil defense equipment	Office of Civil Defense
Surplus foods	Consumer and Marketing Service
Surplus property	Department of Health, Education and Welfare; Office of Civil Defense; Office of Emergency Planning; General Services Administration
Tax assistance	Internal Revenue Service
Temporary housing, shelter	Office of Emergency Planning; American National Red Cross
Tsunami warning	U.S. Coast and Geodetic Survey
Transportation	Interstate Commerce Commission; General Services Administration; Federal Aviation Agency
Urban renewal	Urban Renewal Administration
Veterans benefits	Veterans Administration
Warehousing	General Services Administration
Weather warning	U.S. Weather Bureau
Welfare aids	Welfare Administration

Source: Office of Emergency Planning, January 1966 (changed to Office of Emergency Preparedness, October 1968).

MODIFYING THE LOSS POTENTIAL

The second major group of adjustments operates mainly to reduce or modify the loss potential of human occupance. These adjustments include warnings and subsequent emergency measures designed to remove both life and property from hazardous situations and more permanent devices affecting structures, land use, and the site and situation of settlements.

Warnings

A warning of some kind is required for any action to make human occupance less damage-prone. In order to seek consciously to minimize damage, men must be able to anticipate earthquakes and their effects. However, two very different types of warnings can be distinguished, *hazard-area warnings*, which identify the areas or structures peculiarly vulnerable to earthquake effects, and *event warnings*, which caution about the specific occurrence of an earthquake or some induced effect.

A wide variety of devices can be used for hazard-area warning. Seismic regionalization maps provide a generalized warning to those familiar with them. Such maps exist only in the professional literature and only on very small scale for the continental United States and California. They have been developed in greater detail for other countries where they seem to be more favored by scientists, including the USSR and Japan (Medvedev, 1965). Geologic maps, accompanied by specific interpretation relating slope, subsurface material, and structures to earthquake hazard, are a useful form of warning. Such maps are being prepared for the 1,730 mi^2 Borough of Anchorage, Alaska, on a scale of 1:63,360, and at an approximate cost of $20,000 per sheet and will be accompanied by a landslide-susceptibility map (Ernest Dobrovolny, U.S. Geological Survey, oral communication). Maps on a larger scale (1:24,000 or larger) with appropriate interpretation can be used for incorporating earthquake-hazard warning into the zoning maps of cities in high-hazard areas. Such maps may serve just as a warning or can be given legal status and serve as the basis for land-use restrictions. Other hazard-area warnings include the use of signs similar to those in flood-hazard areas; the incorporation of warnings into deeds, as with the termite hazard in California; and a legal or contractual requirement that property carry earthquake insurance. At present, no agency in the government is specifically charged with issuing hazard-area warnings (U.S. Environmental Science Services Administration, 1965).

The state of hazard-area warning for tsunamis is similar to that of earthquakes. In material prepared for popular distribution, the Coast and Geodetic Survey defines the hazard area as any coast along the Pacific Ocean (U.S. Coast and Geodetic Survey, 1965). Potential danger areas are defined as those within 1 mi of the coast that are lower than 50 ft above sea level for tsunamis of distant origin and lower than 100 ft above sea level for tsunamis of local origin. Definitions of this sort, however, invariably tend to overestimate danger areas and may prove impractical for purposes of guiding evacuation. Cox has developed specific variations of the foregoing rules of thumb (1 percent decrease of height with distance) in order to delineate maximum tsunami runup zones and disaster evacuation zones on maps of the Hawaiian Islands (Cox, 1961). Similar maps could be developed for all coastal areas.

Hazard-area warning for fire already exists for many places in the form of the Sanborn maps that are used to provide ratings for fire insurance for specific buildings. Such ratings are basically by building and they assume the existence of a fire department of certain strength, a water supply, and appropriate facilities. The variables appropriate to earthquake fire hazard would seem to be considerably different. For example, under disaster conditions, with streets blocked and water mains disrupted, relative fire hazard might be governed by such factors as wind direction, existing open space, and sources of emergency water supply.

Event warnings for earthquakes based on predictions of the occurrence of a specific earthquake within a reasonable period of time seem to be many years away, although Japanese scientists appear more optimistic. Their approach was described in a recent interview (*New York Times*, September 22, 1968, p. 26) with Tsunaji Rikitake of the University of Tokyo:

> We finally began to think that if we observe many micro earthquakes, then we are fairly sure that a big one will follow in four or five months. Actually we have succeeded in forecasting with sixty percent accuracy.
>
> The predictions issued through the government attempt to give the approximate time, place, and strength of the quake. For example, the warning may say: There is a possibility of a fairly large quake around [name of town] within four months.
>
> Like long range weather forecasting, this is rather vague. But it gives the local authorities time to take special precautions, like reinforcing weak buildings and strengthening fire brigades.

The timing of a warning is clearly critical. At one end of the time scale, we already possess the capability to say with certainty that an earthquake will occur in a given region if one waits long enough. At the other end of the scale, is the prediction sufficiently accurate for people to believe in and act on far enough in advance of the event to ensure evacuation of population and property? Predictions cannot yet be made to approach the latter degree of precision.

There is no indication that any level of prediction is better than no prediction at all. Consider the impact on the economy and functioning of a large city that receives a warning of a major earthquake occurrence specifying only some time within the next year. Where such a warning actually has been given (possibly the only case in recent record) the results have been mixed. Newspaper reports from Matsushiro, Japan, which has experienced many thousands of light tremors, tell of great tension, a damaged economy, and the rise of cults and splinter religious groups (*New York Times*, January 24 and 30, 1966). Japanese scientists, however, seemed to have a feeling of accomplishment when they forecast in 1966 the occurrence of major tremors based on their monitoring the microseismic activity of Matsushiro (*New York Times*, August 26, 1966). Nonscientific predictions of earthquake occurrence, when believed, have caused greater consternation, a notable example being in London in 1750 (Niddrie, 1961, p. 20-34).

An increased effort in earthquake prediction is, however, apparent, with the establishment of the National Center for Earthquake Research of the U.S. Geological Survey and the Earthquake Mechanism Laboratory of the Environmental Science Services Administration, and with other actions designed to implement proposals for a 10-year program of earthquake-hazard research (Ad Hoc Interagency Working Group for Earthquake Research, 1968).

Event warnings for tsunamis are currently available. In the area near a tsunami-generating earthquake, nature provides some warning either through the perceptible ground motion or by the unusual rising or ebbing of coastal waters. For areas approximately 1,000 mi beyond the earthquake's range of movement the Seismic Sea-Wave Warning System (now the Tsunami Warning System), in operation since 1948, provides from the Honolulu Observatory of the Coast and Geodetic Survey the estimated time of arrival of tsunamis to all the nations of the Pacific. Accuracy of the times of arrival of waves is within 2–3 percent but no capability now exists for predicting either the number or height of waves (U.S. Coast and Geodetic Survey [1965], p. 9).

The two major improvements needed in the present system are the provision of adequate warning for localities near (within 1,000 mi) the point of the tsunami generation and the reduction of the false-alarm ratio for the Pacific area-wide warnings. Considerable experience in providing warnings for locally generated tsunamis has been developed in Japan. Within 20 minutes after the occurrence of an earthquake, an estimate is made as to whether a major or minor tsunami has been generated and of its approximate size. This estimate is made entirely by seismic rather than tidal parameters and is based on regional relationships, empirically derived for Japan, between tsunami magnitude and earthquake magnitude (Cox, 1964, p. 10).

Of greater concern for the United States is the problem of false alarms. Technically these have been rare. In the 20 years of operation of the Seismic Sea-Wave Warning System there have been three warnings issued when later analysis indicated no tsunamis were generated and one when the tsunami was questionable (Cox, 1968, p. 31). But in the eyes of the public and even of some responsible officials, an unnecessary evacuation on the occasion of a wave too small to be seen can be viewed as a false alarm (Havighurst, 1967). From September 1948 to August 1967, the Honolulu Observatory has issued 32 advisory messages of earthquake occurrences designed to alert the warning network. Of the initial messages, 18 were followed by warnings of tsunami generation (Cox, 1968, p. 33). Of the ensuing 14 tsunamis, only 5 caused major material damage or loss of life in the United States. These data by themselves, however, do not indicate fully the false-alarm problem. Despite the operation of the warning system, tsunamis following the Chile earthquake of 1960 and the Alaska earthquake were responsible for 183 deaths. On the other hand, even in the case of the five tsunamis that caused damage or loss of life in the United States, most of the area warned of the imminence of the waves was not damaged.

Cox, after a careful evaluation of the performance of the warning system, concludes (Cox, 1968, p. 61):

> The proper objective of the Seismic Sea-Wave Warning System with its cooperating agencies has been to minimize the hazards of tsunamis, especially the tsunami hazard. In attaining this objective, little or no improvement will result from increasing the number of warnings to include the kinds of tsunamis that have been missed in the past, but much improvement will result from avoiding warnings when they are unnecessary and from minimizing the inconvenience of necessary warning periods. Because the responsibilities of the System now include warning coastlines scattered around and across the Pacific, the minimization of warnings and warning durations depends essentially upon complete adoption of the principle of regional selectivity.
>
> Some completely false warnings have been issued by the System. The potential for issuing false alarms will always exist, of course, but avoidance of some of the false alarms should now be possible on the basis of past experience. Capabilities do not yet exist for eliminating many of the remaining seemingly false alarms, even assuming regional selectivity, and the decisions involved in issuing or not issuing any particular warning will never be easy. However, it seems quite clear that the long-term hazard introduced by the false and seemingly false alarms is greater than the hazard that will be introduced by avoiding some of the more questionable warnings, and hence that the threshold for warning should be higher in the future than in the past.

Event-warning capability also exists in terms of fire hazard. Although the usual array of fire alarms and sprinkler systems can be of assistance in an earthquake, they are also highly vulnerable to the disruption of communications and facilities caused by the earthquake.

Emergency Measures

The rudimentary status of earthquake prediction and the provision for event warnings should not preclude considering the type of actions that may be taken after receiving such a warning. Considering such actions can sharpen our understanding of the types of predictive capability that would be most desirable and can improve the utility of existing tsunami-warning and fire-alarm capabilities. What, then, seem to be feasible emergency actions?

An event warning initiates the mobilization of the disaster organization, an action which, in turn, can lead to effective evacuation of hazardous areas and to the provision for shelter of evacuees. Many aspects of the disaster-organization problem are dealt with at greater length in the companion report of Haas (1970, this volume). However, practically no thought has been given to the problem of evacuation, even assuming that we did have a predictive capability for earthquakes. The closest analogue to evacuation preparations based on earthquake predictions was at Matsushiro where reports tell of residents sleeping fully clothed, prepared to evacuate buildings and move into the street at the first sign of heavy shaking (*New York Times*, May 1, 1966). After a year of tension, and after assurances only five days before that the tremor hazard was over, many residents slept through two hours of "eerie earth rumbling" that presaged the occurrence of a damaging earthquake on August 3, 1966 (Bolt, 1967, p. 138). In much of the world where building construction is of very poor quality, a strategy for minimizing loss of life would call for immediate evacuation of buildings. However, under urban conditions in the United States, it is not clear what constitutes a proper evacuation strategy.

When sufficient warning can be given, the kind of action needed to minimize property damage is clearer. Loose objects and suspended objects can be secured against ground motion. In areas susceptible to major ground movement, valuable property can be removed from the premises. A highly specialized warning system protects the Tokyo–Osaka, Japan, high-speed railroad line. Twenty-five special seismometers placed along the line automatically trigger the signal system to stop trains in case of high horizontal acceleration (Bolt, 1967). After a tsunami warning, a variety of emergency measures is available to evacuate property or minimize the damage from inundation. On riverine flood plains, such measures can reduce property losses by as much as 5 to 15 percent (White, 1964, p. 68).

With reference to urban fire hazard, fire-fighting equipment can be strategically placed so as to minimize possible damage to the equipment and to increase its accessibility to emergency water supplies should there be major ruptures in the system. Rural fire equipment, particularly useful in case of rupture of the urban water supply, can be alerted and moved closer to urban areas. There has been little systematic study of the appropriate disposition of equipment for combating the special fire hazards of earthquakes. Finally, with advance warning, provisions could be made to interrupt electricity and gas flows to reduce the fire hazard.

Even when no warning has been given, losses can be reduced by postearthquake action. The loss of life from an earthquake is clearly related to the amount of search-and-rescue activity, medical aid, and subsequent public-health measures. Emergency repairs can prevent the delayed collapse of structures and, most important, may enable structures to withstand the subsequent effects of aftershocks. Little attention has been paid to the systematic reduction of property loss from aftershocks, an area that is worthy of study.

Structural Measures

Our knowledge about human adjustment to earthquakes is most complete with regard to the construction of buildings designed to resist earthquake stress and, in smaller measure, to resist sea-wave inundation. Fire-resistant construction is also well understood, and these techniques appropriate to the general problem of fire resistance should also be useful in reducing the induced hazard of earthquake-ignited fire. The optimal construction technique to reduce one hazard is, however, not optimal to reduce another. The example of low-mass wood structures resistant to earthquake stresses and vibration but highly susceptible to fire has already been cited. Another example is the installation of sprinkler systems that have great value under normal conditions but, because of the usual means of suspension in ceilings, are highly susceptible to malfunction from vibration and, indeed, may be useless if there is a significant pressure drop because of ruptured water mains.

While much is known about earthquake-resistant construction, several critical aspects are inadequately understood. There is still concern over the behavior of tall buildings during earthquakes, a concern heightened by the shortage of strong-motion instrumentation and by lack of experience with different designs and construction material. Since underlying material magnifies or dampens earthquake effects, the performance of foundations is another factor that is not adequately understood. The lack of such data is reflected in the vigor of the debate over the suitability of developing large subdivisions on man-made fill in San Francisco Bay. Finally, a critical question seems to be: How can an initially good earthquake-resistant design survive the construction process? Practical but more certain methods of supervising construction must be devised to assure compliance of construction to design.

Some progress has been made through the widespread use of building codes and standards. The recommended lateral-force requirements of the Seismology Committee of the Structural Engineers Association of California have been widely adopted on the Pacific Coast and incorporated in the uniform building code of the International Conference of Building Officials. Codes from 19 countries are found in one international listing (International Association for Earthquake Engineering, 1963). However, the existence of adequate codes by no means ensures compliance. Enforcement is hampered by all the usual factors that hamper municipal regulation and general building-code enforcement (Advisory Commission on Intergovernmental Relations, 1966), and added to these are the special problems of the engineering and supervision required for earthquake-resistant construction.

Land-Use Change and Control

A major method of affecting human occupance is to restrict the use of land in hazardous areas so as to minimize the hazard by encouraging changes to land use with less potential for earthquake damage. Thus buildings may be banned on unstable slopes or, in areas of lesser hazard, restrictions may permit low-density residences but prohibit places of public assembly, such as schools.

Three different types of action can be used to change land use: (1) voluntary measures whereby change is encouraged by warning and education, (2) restrictive measures employing either zoning or building codes where there is a demonstrated need to protect the health and welfare of the community, and (3) procurement measures to purchase existing property either outright in fee simple or through less-than-fee-simple rights, thereby restricting the use of such property. The last measure is clearly more effective than voluntary procedures and less ambiguous legally than restrictive ordinances, because care must be exercised that property is not being seized without adequate compensation under the guise of protecting the general welfare.

An extensive literature on flood-hazard zoning provides analogous experience not only immediately useful for dealing with tsunami hazard but related to other earthquake hazard as well (Kates and White, 1961). One demonstrably useful way of thinking about zoning for damage reduction has been to specify three types of zone: (1) a *prohibitive* zone, where any human use that involves permanent structures would imply a clear and present danger both to individuals involved and to others in the community, (2) a *restrictive* zone where some human uses would be permitted, but others would be banned, and finally (3) a *warning* zone, where professional knowledge indicates that one cannot, in good conscience, restrict human activities although the sharing of available knowledge of potential danger with the area's population is advisable.

There is no shortage of tools for effecting land-use change; there is a profound shortage of judgment and will. Although zones, especially those requiring stringent restriction, cannot be easily delineated, local governments are reluctant to develop and enforce any land-use restrictions or undertake land purchase as a means of reducing potential earthquake losses.

A major opportunity for land-use change is the reconstruction period following a disaster. Past experience does not indicate, however, that such opportunities are utilized. Neither Chicago nor Baltimore experienced much change after their great 19th-century fires. Postearthquake San Francisco provided a real opportunity for change: the pre-earthquake plan for city development prepared by Daniel Burnham in 1903 had called for wider streets, squares, plazas, and open spaces. Still another plan for street widening and modification was presented to the city 4 months after the earthquake. Neither plan resulted in any substantial change other than the realignment of a few blocks (Bowden, 1967, p. 469–472). Much of Europe was reconstructed after World War II exactly as it had been before, even to the congested narrow streets and other urban inconveniences. With the need to restore facilities, to encourage economic activity, and to reassert the security of familiar surroundings in the face of disaster, great pressure is generated to put things back exactly as before.

Permanent Evacuation

The most dramatic form of land-use change is permanent evacuation. Urban renewal and redevelopment provide opportunities for permanently evacuating very hazardous areas. Such evacuation can often prove to be an asset, for example, turning a tsunami-threatened waterfront into a park. Total relocation of a whole town is also an alternative, but past experience with this drastic method is not encouraging. In the case of two communities that were moved from a flood plain to a safer area (Leavenworth, Indiana, and Shawneetown, Illinois), neither project was wholly successful and the old and new communities still exist adjacent to one another.

MODIFYING THE HAZARD

Other than limiting human occupance or repairing the actual damages incurred, there are a number of alternative actions that can lessen the hazard. A program can be adopted to identify and locate sites subject to minimal ground motion and to reserve them for public construction. Such sites can be reserved for schools or similar structures in which large numbers of people congregate, or as locations where large buildings should be erected.

Alternative actions reducing hazard from induced earthquake effects are feasible as well. Steep slopes and unstable soils can be stabilized within broad limits. Tsunami barriers can be erected, or land along the shore can be elevated. Fire-fighting systems can be made earthquake-resistant by use of backup alarms and water sources, and by self-sustaining equipment housed in earthquake-resistant structures.

Most of these expensive actions may not be economically feasible. For certain types of soil-stabilization or coastal-engineering structures the first attempts will be clearly experimental, but all the foregoing activities are possible alternatives.

AFFECTING THE EARTHQUAKE MECHANISM

Prospects for controlling earthquake mechanisms are apparently infeasible under present technology. Recently, however, a probable case of inadvertent modification was reported in which the injection of fluids into a deep well is thought to have been responsible for numerous small earthquakes in the Denver area (Healey and others, 1968). Whether men will someday use nuclear explosives or other yet undeveloped devices to relieve stress in advance of a major fracture is highly speculative, but such procedures would clearly require more understanding of the earthquake mechanism than we now possess.

HUMAN ADJUSTMENT TO EARTHQUAKE HAZARD IN ALASKA BEFORE MARCH 1964

Despite the theoretical alternatives for adjusting to earthquake hazard, the types and extent of actual adjustments are always extremely limited. This section examines the extent of adjustment to earthquake hazard in Alaska before the March 27 earthquake, in the light of the foregoing alternatives.

EARTHQUAKE POTENTIAL IN ALASKA

The epicentral area of the March 27 earthquake had not been subjected to an earthquake of comparable magnitude or intensity within living memory. Except for the two great earthquakes of 1899 and 1958, the record shows frequent shaking in Alaska, but little damage. According to Eppley's account (1965, p. 86) of Alaska earthquake experience before 1964, seismic activity in Alaska is greater than in any other state and occurs in two separate zones: one is about 200 mi wide and extends from Fairbanks through the Kenai Peninsula to the Near Islands, and the other extends from north of Yakutat southeastward to the west coast of Vancouver Island. During the 1899 earthquake, the shore area of Yakutat Bay was "raised over a considerable length" and experienced a vertical fault slip of 47½ ft. The shock of the 1958 earthquake near Lituya Bay was severe enough to be felt as far south as Seattle, Washington, and as far east as Whitehorse, Yukon Territory.

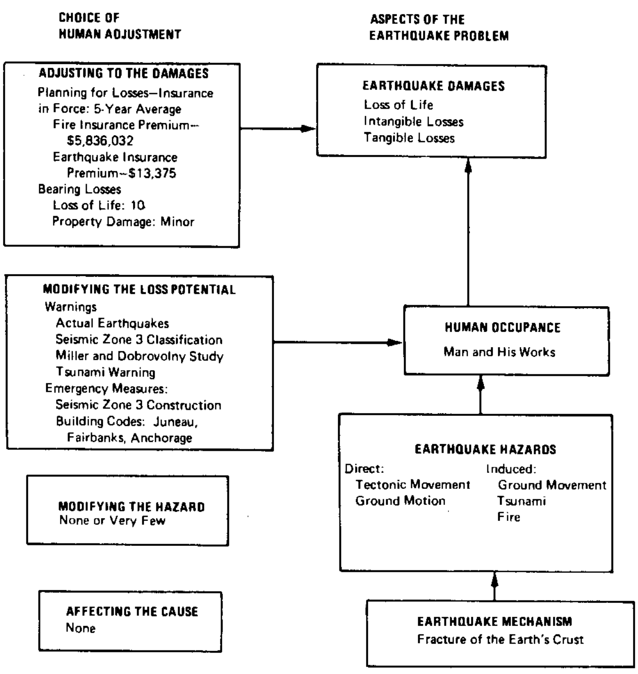

FIGURE 3 Actual human adjustment to earthquakes in Alaska before 1964.

Alaska's historical experience with earthquakes explains the inhabitants' pre-1964 attitude of ignoring serious earthquake hazard. A natural paradox existed: earthquakes occurred very frequently, but only two great earthquakes had occurred in over 60 years, and those had been in the southeastern seismic belt in sparsely inhabited areas.

PERCEPTION OF EARTHQUAKE HAZARD

During the past decade a considerable body of knowledge has accumulated on how inhabitants perceive natural hazard. Although direct interview data are available for residents of hazardous flood, storm, drought, tsunami, snow, and tornado areas, no such data are available on perception of earthquake hazard. From published sources and informal interviews with residents, we learn that knowledge of earthquakes was very common; to Alaskans, occasional tremors were part of the environment. Even by professionals, who may have made hazard estimates as part of their activities, only one warning has been clearly identified (Miller and Dobrovolny, 1959).

PREVALENT ADJUSTMENTS BEFORE MARCH 1964

Without major field research, it is difficult to reconstruct the pattern of human adjustments prevalent in Alaska before the earthquake. From the limited published data available, the kinds of human adjustment at that time may be diagramed as in Figure 3.

No attempts were made to control earthquake mechanisms; even measurement of their activity was rudimentary, for there were in Alaska only a few seismograph stations before 1964, and no strong-motion instruments. Nor is there evidence that any serious attempts were made to reduce hazard as we have defined it, by selecting stable sites for construction, stabilizing soil and slopes, erecting seawave barriers, or mounting special fire protection. Some soil and slope stabilization was done incidentally, in order to provide good foundations for structures, but not apparently in conscious response to earthquake hazard. One example of this unconscious stabilization is the Shell Oil Tank Farm at Anchorage where an 8-acre swampy area to be used as a construction site was filled with highly compacted gravel, which apparently later provided considerable protection from ground motion. In general, Alaskans adjusted to damages or, in limited ways, attempted to reduce the loss potential.

Adjusting to the Damages

Alaskan experience in bearing past earthquake losses was limited. Since the turn of the century there were only ten deaths (all from tsunamis), and despite frequent shaking, property damage was small.

The degrees of preparation for losses can only be surmised, and there are no adequate estimates of the amount of earthquake insurance in force in Alaska. Premium totals averaged $13,375 for the 5 years before the earthquake; during the same period, totals for fire-insurance premiums averaged $5,836,032 (Howard Kunreuther, personal communication, 1966).

Provisions for relief in disaster do not seem atypical for the size of the population. As in many other places, Civil Defense was strongly oriented toward threat of nuclear attacks, and the state disaster plan was still in draft form and was being reviewed by the various state agencies and departments. The only Red Cross chapter with paid officials was in Anchorage and operated 14 centers throughout the state (Daniel Yutzy, personal communication, 1966). All civilian capability for sharing and mitigating losses in case of disaster was clearly overshadowed by the tremendous military potential.

Modifying the Loss Potential

The frequency of tremors provided a basic kind of hazard-area warning for much of Alaska. Formal or detailed hazard-area warnings were almost nonexistent. Seismic regionalization maps did not exist other than in the form of maps showing the location and magnitude of the epicenters of previous earthquakes. In a sense, the classification of Alaska by the Uniform Building Code as Seismic Zone 3 provided additional hazard-area warning. The Miller and Dobrovolny (1959) study has been frequently cited for its prophetic warning about the potential of sliding in the Anchorage area. This study noted that "... the Bootlegger Cove Clay—an unstable material when wet, that can be dislodged by some triggering action—underlies stratified sand and gravel" (p. 103). However, the study was published as a bulletin of the U.S. Geological Survey, which has a very limited professional circulation. Of the 2,800 copies printed, no more than a couple of hundred were distributed in Alaska before the earthquake and these cannot be considered as a warning to any significant section of the population. Surficial geologic mapping is another form of professional warning, but such maps were only available for Anchorage. Only one use of professional advice relating to site selection in Anchorage has come to light: a large hotel, planned for construction on the bluff, was not built because soil investigation suggested that the required stabilization would be too expensive.

The only event-warning system in existence was the Seismic Sea-Wave Warning System. Stations at Attu, Adak, Unalaska, Kodiak, and Sitka provided information about tides; the seismograph at College provided seismographic data. The Seismic Sea-Wave Warning System was least effective for locally generated tsunamis.

Arrangements for emergency measures, although rudimentary, were no worse than those found elsewhere. No community had a natural-disaster evacuation plan, and plans that had been developed were related strictly to nuclear attack. One minor exception to this was a single paragraph that appeared in the "Greater Anchorage Emergency Instructions." Residents of Anchorage were informed in case of earthquake:

> If you are indoors, remain inside. Protect yourself by crouching under a well-built table, or by standing in the doorway, closet, or hallway. This will prevent walls, ceiling, or other debris from falling on you. If you are outside: avoid standing by ornamented, faced, or brick walls which might fall or drop. If possible, get into a doorway or stand in the middle of the street.

Leading cities in Alaska—Anchorage, Fairbanks, and Juneau—all had recent building codes that included Seismic Zone 3 earthquake requirements. The National Board of Fire Underwriters reports that when earthquake provisions were first adopted, plans were sent out of the state for review for building-code compliance, but in the last few years this review had been done within the Anchorage Building Department. The report concludes, "therefore the bulk of the major buildings in Anchorage should have had earthquake resistant design and construction" (National Board of Fire Underwriters, 1964, p. 8).

HUMAN ADJUSTMENT TO EARTHQUAKE HAZARD IN THE EXPERIENCE OF THE MARCH 27 EARTHQUAKE

THE MARCH 27 EARTHQUAKE: DISTINCTIVE FEATURES

The magnitude of the earthquake of March 27, 1964, has been estimated variously at 8.3-8.4, 8.4, and 8.5-8.75 on the Richter scale. This extremely large event clearly exceeds all others in the recorded history of the North American continent. The energy liberated by the earthquake has been estimated as the equivalent of 100 underground 100-megaton nuclear explosions placed in line (Press and Jackson, 1965, p. 868).

Doubt exists as to the specific nature of the earthquake mechanism involved. Two possible fault planes are suggested by instrumental seismology: one is nearly horizontal and the other nearly vertical. Available data are inadequate to determine which is the more reasonable hypothesis.

EARTHQUAKE HAZARD: DISTINCTIVE FEATURES

Two types of direct hazard have been distinguished: tectonic movement of uplift and subsidence, and ground motion.

With respect to both types, the Alaska earthquake was exceptional. Crustal deformation associated with the earthquake was more extensive than that related to any known previous earthquake. An area of at least 70,000 mi^2 and possibly 110,000 mi^2 was affected by vertical tectonic movement during the earthquake. Over wide areas, net elevation and depression exceeded 6 ft; locally, vertical movement exceeded 30 ft on the land surface and 50 ft on the sea bottom (Hansen and others, 1966, p. 14–17).

Similarly the duration of strong ground motion was exceptional. The El Centro earthquake of 1940, frequently used as a basis for earthquake-resistant design in California, lasted approximately 25 seconds (National Board of Fire Underwriters, 1964). The San Francisco earthquake of 1906 has been estimated to have lasted 1 minute (Hansen and others, 1966, p. 3). The Alaska earthquake of 1964 produced shaking for at least 3–4 minutes (timed estimates range from 1½ to 7 minutes) of which about 1 minute consisted of strong motion (Hansen and others, 1966, p. 3; oral communication, George Housner, 1967).

Induced effects of the earthquake added to the nature of the hazard. Extensive ground cracks and sliding (land slides and submarine slides) were initiated by the prolonged vibration, affecting unstable outwash materials and a deeply fiorded coast. Tsunami hazard was complex. A major tsunami was generated and arrived at some coastal areas near the epicentral area within half an hour of the earthquake (Spaeth and Berkman, 1967). A number of other destructive waves triggered by submarine sliding were experienced almost instantaneously with the earthquake. Fires were notably few; the only serious fires occurred in waterfront oil-storage tanks, where fires were ignited and spread primarily from the effects of wave action. The report of the National Board of Fire Underwriters attributes the absence of fire "in part to the general failure of gas and electric systems, eliminating one fuel and an important source of ignition" (National Board of Fire Underwriters, 1964).

The complex nature of earthquake hazard was never more manifest than in the Alaskan event (Table 2). A concise summary of effects on specific communities was prepared by the Geological Survey (Hansen and others, 1966, p. 17–19):

> Earthquake damage to the cities, towns and villages of southern Alaska was caused by direct seismic vibration, ground breakage, mud or sand emission from cracks, ground lurching, subaerial and submarine landslides, fires, sea waves, and land-level changes (Grantz and others, 1964). Not all these factors caused damage in every community. Some communities were devastated by only one; the village of Chenega, for example, was destroyed by a sea wave. Overall, landslides probably caused the most damage to manmade structures and property, but sea waves took the most lives.
>
> Effects of one factor cannot always be separated from effects of another. Thus, at Seward (Grantz and others, 1964, p. 15; Lemke, 1966 [1967]) the waterfront was racked by vibration, slides, sea waves, fires, subsidence, and ground cracks. All these factors contributed significantly to the havoc, and all in combination wiped out the economic base of the town. Comparable damage at Valdez, plus the threat of recurrent damage in the future, forced relocation of the village and abandonment of the present townsite (Coulter and Migliaccio, 1966).
>
> Among the larger towns, only Cordova was significantly damaged by uplift, but the native village of Tatitlek and several canneries and residences at Sawmill Bay on Evans Island were also adversely affected by uplift.
>
> Most of the small coastal villages in the earthquake zone were damaged chiefly by sea waves, subsidence, or both (Kachadoorian, 1965).
>
> The native villages of Chenega, Kaguyak, Old Harbor, and Afognak, all remote waterfront fishing villages, were nearly or completely destroyed by waves, especially Chenega, population 80 before the earthquake. There, 23 lives were lost, and only the schoolhouse remained of the village's buildings. Six homes were left standing at Old Harbor, where there had been about 35. There were nine homes in Kaguyak and a Russian Orthodox Church; all were carried away or destroyed. At Afognak, four homes, the community hall, and the grocery store were carried away by waves; several other homes were moved partly off their foundations (Alaska Department of Health and Welfare, 1964); and subsidence made the townsite uninhabitable. The sites of Chenega, Kaguyak, and Afognak have been abandoned in favor of new townsites.
>
> Direct vibratory damage was significant chiefly in Anchorage and Whittier, although minor vibratory damage was widespread through the area of intense shaking. At Anchorage several buildings were destroyed by vibration, and nearly all multistory buildings were damaged (Berg and Stratta, 1964; McMinn, 1964; National Board of Fire Underwriters and Pacific Fire Rating Bureau, 1964; Hansen, 1965). At Seward, Valdez, and Whittier, ground vibrations ruptured oil storage tanks, and the spilled petroleum quickly caught fire.
>
> Ground breakage caused extensive damage in Anchorage, Seward, Whittier, and Valdez, not only to buildings but also to buried utilities such as water, sewer, gas, electric, and telephone lines. Cracked ground resulted from the passage of sinusoidal seismic waves through the soil, from lurching, from lateral spreading of soils under gravity, especially near the heads of landslides, and from differential settlement of alluvial and artificial fills.
>
> Mud and sand were pumped from ground cracks throughout the damage zone where water tables were shallow in saturated granular soil. At Valdez, and to a lesser extent at Seward (Forest Acres), large volumes of sediment were ejected from cracks into cellars and crawl spaces (Coulter and Migliaccio, 1966; R. W. Lemke, oral communication, 1965).
>
> Submarine and subaerial landslides triggered by the earthquake caused spectacular damage in Anchorage, Seward, Valdez, Whittier, and Homer (Engineering Geology Evaluation Group, 1964; Grantz and others, 1964; Shannon and Wilson, Inc., 1964; Hansen, 1965; Lemke, 1966 [1967]; Coulter and Migliaccio, 1966; Kachadoorian, 1965; Waller, 1966). Four large slides in built-up parts of Anchorage were caused by failures along bluff lines in soft, sensitive silty clay whose water content at critical depths exceeded its liquid limit. Failure at Anchorage was mostly subaerial, although the large Turnagain Heights slide failed partly below sea level and slipped part way down the mudflat into Knik Arm of Cook Inlet. At Valdez and Seward, violent shaking spontaneously liquified granular deltaic materials; slumping which initiated well below sea level carried away the waterfronts of both towns. The seaward slopes of the deltas, moreover, were left less stable after the earthquake, than they were before.

EARTHQUAKE DAMAGE: DISTINCTIVE FEATURES

Loss of Life and Injury

One hundred fifteen persons lost their lives in Alaska, and 82 bodies were never recovered. About 40 persons suffered major physical injury (Lantis, 1970, this volume). At least 11 persons died at Crescent City, California, and 4 along the Oregon coast. One injury was recorded in British Columbia.

Death came primarily from the sea. Ninety-six persons were drowned or swept away by the tsunamis; 13 were crushed by wave-tossed debris or vanished in the coastal slides. Thus almost the entire death toll was essentially due to the coastal location of the human occupance (Lantis, 1970, this volume).

Significantly, the death rate was relatively low in relation to the magnitude of the event, first because the country was sparsely settled, and second because the earthquake occurred fortuitously on a holiday, Good Friday, at a time of day when many had left public buildings and were en route to their homes. One can only imagine the tragedy that might have occurred had Government Hill School been open and in session, or had the newly built Four Seasons Apartment House in Anchorage been occupied. Dr. Martha Wilson (1964), director of the Alaska Native Service Hospital (later renamed the Alaska Native Medical Center) in Anchorage, noted:

> Had we planned this earthquake, we could not have chosen a better time. In the late afternoon of Good Friday, many office buildings were closed, and many persons were driving home in their automobiles, a relatively safe place to be. Everyone was awake and most persons were clothed. Even more important, they had their shoes on, usually an important point in Alaskan survival. Fortunately, on this day, and during the following week, temperatures ranged from 20°F to 30°F. During approximately four months of the year, the weather is severe enough to cause fatalities in a disaster situation if suitable clothing or shelter is not immediately available. Building fires for warmth in this disaster would probably have been as hazardous as the freezing cold. When the quake started coming, the electricity went off immediately. Had it struck at the same time of day three weeks earlier, it would have been dark, and no one without a flashlight would have been able to see to rescue children, avoid falling objects, escape from breaking and falling structures, or avoid the numerous crevasses which were opening and grinding closed in the earth (p. 853).

Intangible Losses

Each death or injury is accompanied by a pattern of grief and disruption that may extend far beyond the immediate family. Individual psychic distress was also magnified by the collective distress that followed the virtual wiping out of a number of native villages or the forced relocation of an entire town, as in the case of Valdez. Much of this profound human loss is documented in the narrative of human response.

One intangible loss originally feared did not develop. It was felt that the Alaska earthquake would impair confidence in the future of Alaska and further upset the already shaky balance between population and economy. Instead, something of a reverse effect on Alaska's future has been documented (Rogers, 1970c, this volume). However, specific losses of industry, such as the canneries at Seldovia and Kodiak, may disrupt the economy of these communities in ways that will not be easily countered. Biological effects, such as the impact on shellfish communities, still need to be measured, but in an economic sense earlier fears have not materialized.

Tangible Losses

The total losses incurred in the Alaska earthquake will never be known. Only scattered estimates exist for personal-property losses, or, for example, economic injury from production losses. The most common means of estimating damage (no consistent means was employed), cost of restoration, generally tends to bias estimates upwards because it does not account for the depreciation in the replaced facilities. The great variance in estimates between those made immediately after the earthquake and those made subsequently is documented elsewhere (Kunreuther, 1970, this volume). Changes in damage estimates and actual federal expenditures are given in Table 3. The classification of damages is somewhat different from that for other natural hazards, a difference that arises from the preponderance of public expenditure in Alaska, the peculiarities of the reconstruction effort, and the sources of financial aid for that effort. Roughly two-thirds of the damages occurred in the public sector. Included in these figures are estimated losses of revenue to various governmental units, as well as extraordinary operating expenses occasioned in the public sector by the earthquake.

After reviewing carefully all the conflicting damage estimates made in connection with the earthquake, Kunreuther places "the total of all tangible losses at slightly over $300 million" (Kunreuther, 1970, this volume). This total, though large in terms of Alaska's economy and resources, is small in relation to the resources of the nation or even the annual toll of damage from geophysical hazard, now averaging between $2 and $3 billion a year. In the same year as the Alaska earthquake, hurricane damage alone in the United States was estimated at half a billion dollars.

In view of the magnitude of the geophysical event, tangible losses from the Alaska earthquake were small, but the distribution of such losses within Alaska was strikingly uneven. In absolute terms, 60 percent of the damage occurred in the Anchorage area. In relative terms, the villages of Chenega, Kaguyak, Old Harbor, which were totally destroyed, and Valdez and Seward, with per capita losses of $7,000 and $11,060 respectively, suffered maximum damage.

TABLE 2 Summary of Earthquake Damages to Alaskan Communities

Place	Population[a] 1960	Population[a] 1964	Deaths[b]	Type of Structure Damaged[c]: Homes	Business	Military	Harbor	Water Supply	Other Utilities	Highways	Airports	Buildings Damaged[d]	% of Premises Damaged[e]	% of Townsite Acreage Damaged[e]	Real Property Damage Estimates (Millions of Dollars): Federal Property	State and Local Government Property	Private Property	Total	Total Damage per Capita[f]
South Central Alaska[g]	*107,916*	*116,608*	*115*												71.0	163.0	77.0	311.0	2,660
Anchorage District	*82,833*	*94,666*	*9*																
Anchorage School District	64,226	76,000	8	X	X	X	X	X	X	X	X	1,500	10	10	2.3	72.3	42.6	117.2	1,540
Fort Richardson	11,013	16,500	0	–	–	–	–	–	–	–	–	–	–	–	24.4	–	–	24.4	1,480
Elmendorf AFB	5,084		1	–	–	–	–	–	–	–	–	–	–	–					
Girdwood	63	100	0	X	X	–	–	–	–	–	–	5	–	–	–	–	.1	.1	10,000
Portage	71	100	0	X	X	–	–	0	–	X	–	25	–	20	–	–	.3	.3	3,000
Chugiak	51	50	0	–	–	–	–	X	–	–	–	15	–	5	–	–	.1	.1	400
Eagle River	130	200	0	–	–	–	–	X	–	–	–								
Kodiak District	*7,174*	*8,191*	*19*																
Kodiak	2,628	3,300	15	X	X	X	X	X	X	X	X	130	10	30	–	5.9	3.7	16.4	2,480
USN and USCG	2,743	3,000													6.8	–	–		
Afognak	190	200	0	X	X	–	X	X	0	X	–	25	60	10	–	–	.8	.8	4,000
Kadiak Fisheries Cannery	–	2	0	X	X	–	X	X	X	–	–	15	100	–	–	–	.7	.7	–
Ouzinkie	214	205	0	X	X	–	X	–	-	–	–	5	15	10	–	–	.3	.3	1,500
Old Harbor	193	200	1	X	X	–	X	X	0	–	–	35	90	–	–	–	–	–	–
Kaguyak	36	45	3	X	X	–	–		–	–	–	15	100	–	–	–	–	–	–
McCord	–	8	0	X	X	–	–		–	–	–	–	–	–	–	–	–	–	–
Kenai–Cook Inlet District	*6,097*	*7,943*	*0*																
Homer	1,247	1,500	0		X		X			X		55	–	–	–	1.4	1.3	2.7	1,800
Seldovia	460	500	0	X	X		X		–		X	5	–	–	–	1.3	1.2	2.7	5,400

Palmer-Wasilla-Talkeetna District	*5,188*	*6,123*	*0*																
Seward District	*2,956*	*2,639*	*12*																
Seward	1,891	1,500	12	X	X	X	X	X	X	X	X	120	20	100	.2	11.9	5.5	16.6	11,060
Hope	44	50	0	X	–	–	–	X	–	–	–	25	–	30	–	–	.3	.3	6,000
Valdez-Chitina-Whittier District	*2,844*	*2,423*	*73*																
Valdez	555	1,000	32	X	X	–	X	X	X	X	X	245	–	100	–	3.5	3.5	7.0	7,000
Whittier	809	70	13	X	X	X	X	X	X	X	X	10	80	35	2.3	–	2.9	5.2	–
Port Whittier (U.S. Army)	303																		
Chenega	61	100	23	X	–	–	–	–	–	–	–	20	100	100	–	–	–	–	–
Tatitlek	96	100	0	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–
Ellemar	–	1	0	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Port Nellie Juan	–	3	3	–	–	X	X	–	–	–	–	–	–	–	–	–	–	–	–
Point Nowell	–	1	1	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Port Ashton	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cordova-McCarthy District	*1,759*	*1,973*	*2*																
Cordova	1,128	1,500	0	X	X	–	X	X	X	–	–	85	20	10	–	.3	.8	1.1	733
FAA Airport	–	40	0	X	X	–	–	X	X	X	X	–	–	–	–	–	–	–	–
Point Whitshed	28	30	1	X	–	–	–	–	–	–	–	10	–	–	–	–	–	–	–
Cape St. Elias	–	4	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

[a]Population estimates prepared by George W. Rogers (1970a and b, this volume) from U.S. Census, State of Alaska, Employment Security Division estimates, and other sources.
[b]Adapted from Hansen and others, 1966; revised by Margaret Lantis and others.
[c]Adapted from Hansen and others, 1966, Table 1.
[d]Based on an unpublished survey by the Housing and Home Finance Agency and on estimates in various damage reports; values rounded to the nearest five units.
[e]Adapted from Hansen and others, 1966, Table 1; revised from data in sources described in footnote *d* and rounded to nearest 5 percent.
[f]Based on an analysis of damage estimates from all known sources, compiled and revised with the assistance of H. Kunreuther and N. West.
[g]Except for the number of deaths, town and district figures do not equal the total for south central Alaska because some sources exclude intercity highway and transportation **losses**.

X = structural damage observed.
– = no information.

TABLE 3 Changes in Damage Estimates over Time and Actual Federal Expenditures (Millions of Dollars)

	Damage figures		Federal expenditures[a]
	Initial estimate[b] (April 1964)	Latest estimate[b] (December 1964)	September 1966
Public sector	318	234	190
Private sector	257	77	114
Shortfall of revenue	27	14	14
Extraordinary operating expenses	18	10	8
Total	620	335	326

[a]Individual federal agencies.
[b]Office of Emergency Planning.

Source: H. Kunreuther, 1970, this volume.

EXPERIENCE WITH PREVALENT ADJUSTMENT

Bearing the Loss

How did Alaskans bear their unexpected losses? Individually, as by community, losses were very uneven. There is little equity in natural disaster. In the aggregate, however, Alaskans bore little in the way of losses. Inflows of federal funds exceeded some of the loss estimates. For example, losses from damage to real property in the private sector, estimated at $77 million, were relieved by federal expenditures that, through September 1966, totaled $114 million (Kunreuther, 1970, this volume). In addition to the net inflow of funds, earthquake reconstruction provided a needed stimulus to a lagging economy. Kunreuther has noted that a surplus of housing existed in preearthquake Anchorage, and Rogers has found that the earthquake reversed a downward trend in employment in almost all sectors.

In all fairness, the lavish aid to Alaska was not motivated solely by the desire of the federal government to share the Alaska earthquake losses with the people of Alaska. It represented the government's long-term commitment to assist economically depressed or undeveloped areas, in much the same fashion as its commitment to Appalachian regional development. Nevertheless, the net result was to create a substantially new situation, for never before had relief from losses in a natural disaster of this magnitude been so heavily subsidized from external sources.

If the real costs, at least in tangible damages, of the Alaska earthquake were only partly borne by the Alaskans themselves, what might be said about their attitude toward bearing damages? Much has been said of the Alaskan ability to weather hardship, their fierce independence, and their "frontier spirit."

Daniel Yutzy suggests that many Alaskans believe such characteristics were an important factor in the rapid recovery of Anchorage. He cites expressions such as: "This is frontier country, and we are used to hardship. Even those of us living in towns spend our weekends roughing it. We know how to take care of ourselves." But Yutzy goes on to conclude that the so-called "frontier spirit" of Alaskans living in Anchorage, at least, is largely a myth (Yutzy and Haas, 1970, this volume).

Evidence of the frontier spirit can be more clearly substantiated from the chronology of events and the narrative account of behavior in some of the smaller communities. Outstanding examples of self-reliance and resourcefulness were found at Kodiak and some of the native villages. But side by side with the attitudes of self-reliance that the frontier spirit may have generated was a clear expectation of massive assistance. This attitude was generated in part by Alaska's history as a ward of the government: literally, in the case of many native Alaskans, and symbolically, in terms of the Alaskan history of economic and political relations with the federal government. Rogers has characterized these relations in one period, as a colonial state, and in another period, as a garrison state. In both cases, these are states of dependency (Rogers, 1962).

Sharing Losses

In addition to the $326 million federal expenditure in disaster and reconstruction assistance (Table 3), losses were mitigated in other ways. Total losses paid under earthquake coverage amounted to $72,814, a very small amount that reflected the limited coverage. Under other coverages (fire and inland marine), sizable losses of more than $3 million were incurred from various induced effects of the earthquake (K. V. Steinbrugge, personal communication, 1967). The Red Cross expended over $1 million in earthquake relief and The Salvation Army spent close to $.5 million. Of the major nonaffected areas in Alaska, assistance came from Fairbanks and Juneau. The formal and informal generosity of Americans in the lower 48 was quite impressive: they gave at least half a million dollars to various funds

(Bartlett, 1964. Also Appendix, this volume). Port Lions, constructed to replace Afognak, was built with donated lumber. Communications to Alaska were seriously overburdened by the massive outpouring of gifts, some of them useless. A serious problem was handling the inflow of unneeded clothing donated by concerned Americans from all over the United States.

Warning

The earthquake itself provided the only warning of tectonic movement, ground motion, landsliding, and submarine sliding. The devastating waves from submarine slides that struck Seward, Whittier, and Valdez occurred almost simultaneously with the earthquake.

The effectiveness of tsunami warnings was mixed. For the native villages, the earthquake or the ebbing of the tide in the bay served as warning. Kodiak, Seldovia, and Crescent City, California, all received some warning, in part originating from the Tsunami Warning System. Only Crescent City, 1,380 mi and 4 hr away from the epicenter, received its warning through the prearranged formal channels. Dissemination of and response to the warnings were also mixed, with tragic results. The actual response to tsunami warnings in certain communities is summarized in Table 4.

Emergency Measures

The extensive military establishment in Alaska was a great source of strength and undertook emergency measures to reduce the loss of life, to ease immediate suffering, and to restore needed services quickly. This source of emergency support makes it very difficult to evaluate the efficacy of the emergency action taken by the civilian sectors, though in general those civilian agencies that normally deal with emergency situations performed extremely well in their areas of competence. In Alaska's harsh environment, for example, those who maintain the flow of utilities do so under difficult natural conditions. In manpower and technical knowledge, therefore, Alaskans were well equipped to effect the immediate restoration of needed equipment, transmission lines, and similar items. However, in the activities for which there were no precedents, tasks had to be first recognized and new organizations contrived to deal with them. The confusion over search-and-rescue activity on the first night in Anchorage, and the emergence of the mountain-rescue squad, is an example of this kind of development (Yutzy and Haas, 1970, this volume). In the native communities, whose residents were used to considerable improvisation and outdoor living, there was still much variation in the degree of comfort and safety in which they spent their first night after evacuating the coastal communities. In brief, organizations in which emergency functions were a regular activity (military, public utilities, and the like), seemed to perform extremely well. Where the tasks either did not fall easily within established jurisdiction of an organization or where appropriate organizations did not exist, then men improvised with varying success.

Several examples of emergency actions designed to reduce losses have come to light. The movement of boats out of harbors before the arrival of the tsunami prevented serious damage. Emergency reinforcement of the Shell Oil Company tanks at Anchorage provides an example of emergency measures to reduce property damage that could have been increased by aftershocks. Here damage to the tanks resulted from vibration of the oil within them. Heavy snowfall and the subsequent shocks of varying intensity continued to weaken the tanks progressively. Major damage to two tanks had been avoided by a series of emergency props and supports that had been placed immediately after the earthquake, but the company estimates that additional cost of repairs from progressive weakening of one of the tanks by aftershocks amounted to $29,000. Total failure was, however, prevented by the temporary measures.

Structural Measures

In general, buildings performed well. The larger buildings were new and of earthquake-resistant design. The low mass and wooden construction of older structures resisted vibration and ground motion. Because no structures seem to have been designed to be tsunami-resistant, extensive damage occurred to buildings in the path of tsunamis. There were no real tests of structural survival from fire except for those of oil-storage tanks.

Where buildings failed to survive the ground motion, the failures can often be attributed to poor construction and to lack of attention to detail. This inadequacy is a special problem in Alaska; the building season is very short, and much construction is done in haste. A significant cause of the failure of structures, even of structures designed according to the existing codes, was the critical lack of supervision and care in construction. On the basis of limited investigation, the National Board of Fire Underwriters (1964, p. 17) reported:

> The code adopted in Anchorage from the earthquake resistant standpoint is considered a satisfactory code. However, the performance of many large structures, particularly those using the most modern construction techniques, was not as satisfactory as might have been expected. One or more of the following factors were responsible for individual building failures, . . . (a) lack of professional plan checking, (b) inadequate field inspection, (c) faulty construction techniques, and (d) inadequate soil analysis.

The engineering volume of this report analyzes in detail the nature of engineering failure, which, with hindsight, is a measure of the effectiveness of earthquake-engineering design and construction, and of the enforcement and adequacy of building codes.

TABLE 4 Warnings of the March 27, 1964, Tsunami with Estimated Time of Arrival, Source, Dissemination, and Response

Place	Estimated Arrival Time (GMT)	Source SSWWS	Source Other	Dissemination	Response
Afognak	–	–	Shortwave radio; ebbing tide	None organized	Evacuation mixed
Kaguyak	–	–	Villager expected wave from experience on Adak	Villager gave alarm	Shore evacuated but 3 deaths
Kodiak	0435	Fleet Weather Central	Amateur radio at Cape Chiniak	Fire alarm; police car; spotty – no electricity	Confusion as to warning, but no deaths in city proper
Old Harbor	–	–	Expected from previous experience; Kaguyak radio report	–	Village evacuated well in advance; one oldster living across the bay killed
Ouzinkie	–	–	Observations of bay	–	No loss of life
Seldovia	–	–	Civil Defense via RACES; Homer radio	Fire siren; word of mouth	Evacuation complete by 2000
Crescent City	0739	CDO advisory warning	–	Door-to-door 10 min before first wave	Early return to area; 11 deaths
Port Alberni	0800	Not in SSWWS	Arrival of first wave	RCMP, Dept. of Social Welfare, and volunteers	Evacuation under way by arrival of second wave; no loss of life or serious injury

Abbreviations used:
GMT Greenwich Mean Time
SSWWS Seismic Sea-Wave Warning System
RACES Radio Amateur Communications Emergency Service
CDO California Disaster Office
RCMP Royal Canadian Mounted Police

Sources: Norton and Haas, 1970, this volume; Spaeth and Berkman, 1967; White, 1966.

ADJUSTMENTS ADOPTED AS A RESULT OF THE EARTHQUAKE EXPERIENCE

Adjusting to Damages

Do Alaskans expect substantial earthquake losses in the future? This question is difficult to answer. From a scientific point of view, neither the past history of earthquakes nor the best intuitive estimates of the scientists on this Committee suggest that adult Alaskans should necessarily expect within their lifetimes an earthquake comparable in magnitude, intensity, and location to that of March 27. George Housner (personal communication, 1967) has estimated that the recurrence interval of ground shaking equal to or greater than that at Anchorage in 1964 ($\geqslant$ ¼ g) for any location in Seismic Zone 3 is 250 years, although regions in the vicinity of large active faults may have shorter recurrence intervals and other regions may have longer intervals.

From a behavioral point of view, studies of human response to other hazards indicate that many people who have experienced a major natural disaster do not expect to be involved in another one. Often the net effect, instead, is to encourage a feeling of safety. This feeling could only be reinforced by published interviews of the type headlined "EARTH TENSION GONE, HE SAYS." This news story cites Father Joseph Lynch, a seismologist at Fordham University, as the authority for the following conclusion ventured by Lowell Thomas, Jr.: "Presumably, the area [Anchorage] has settled to such an extent that the tension in the earth is gone and will not build up for hundreds of years" (*Anchorage Daily News*, April 2, 1964, p. 8).

The earthquake has increased interest in insurance both in Alaska and in Washington where Alaska's legislators have been in the vanguard of congressional demands for an investigation into federally subsidized or supported hazard insurance.

The earthquake resulted in the development of new forms of disaster assistance. A major innovation was the provision of funds to retire mortgages, in excess of the first thousand dollars, on one- to four-family homes that had been severely damaged or destroyed. Greatly liberalized loans were made available from the Small Business Administration. In view of the very high interest rates in Alaska and because such loans could be applied to the retirement of debt not directly connected with the earthquake damages, these loans proved to be of great assistance in minimizing the burden of damages in the private sector. In a few cases, particularly in some businesses, borrowers might even have found the loans to be a windfall that left them financially sounder after the disaster than before it (Dacy and Kunreuther, 1969).

Another distinctive form of assistance was the continuation for two more years of the grants given to Alaska in 1959 to ease her transition into statehood. This continuation was designed to cover an estimated $23.5 million expected shortfall in revenue caused by the earthquake or by extraordinary operating expenses occasioned by it.

The earthquake also led to the birth of an extraordinary governmental institution designed to speed the reconstruction process, to coordinate the myriad activities of governmental agencies with the state, and to consider as well the task of reconstruction within the framework of future federal planning for Alaska. The Federal Reconstruction and Development Planning Commission for Alaska came into being through Executive Order 11150, on April 2, 1964. The commission was unique in its organization; although responsible to the President, it was chaired by Senator Clinton P. Anderson, the only legislator on it. The choice of Senator Anderson as chairman was based partly on his experience with relief programs during the 1930's and partly on his membership on the Senate Interior and Insular Affairs Committee. The appointment of an extremely influential, capable, and respected member of the Senate provided an informal legislative liaison that probably reflected the President's understanding both of the ways of Congress and of the ways of the executive branch of the government. Other members of the commission were the secretaries of Defense; Interior; Agriculture; Commerce; Labor; and Health, Education, and Welfare; as well as the administrators of the Federal Aviation Agency; the Housing and Home Finance Agency; and the Small Business Administration; the chairman of the Federal Power Commission; and the director of the Office of Emergency Planning. The staff comprised personnel on loan from federal departments and agencies. A counterpart commission was also set up by the Alaska state government.

An outstanding feature of the postearthquake experience was the considerable speed of reconstruction. In part, this speed was a function of the environment itself. With a limited construction season, some things had to be accomplished, if the effects of the damage were to be minimized. The Reconstruction Commission itself was a major element in accelerating the process. It seems to have been particularly effective in inducing some agencies to see new ways of doing things and to cut the time involved in their customary procedures (Eckel and Schaem, 1970, this volume).

Reducing the Loss Potential

Hazard-area warning in Alaska has improved considerably in technical knowledge. The Reconstruction Commission appointed a Scientific and Engineering Task Force which, with its field team, provided a set of risk maps for Anchorage, Homer, Seward, and Valdez (Eckel and Schaem, 1970, this volume). These risk maps were based on extensive geological studies, particularly on those of Miller and Dobrovolny (1959), which already existed for the Anchorage area, and on the extensive Shannon and Wilson soil studies (1964, a–e), which were made immediately after the earthquake. The hazard-mapping program is continuing, at least for the borough of Anchorage.

New instrumentation is also available today in Alaska. The existing Tsunami Warning System for predicting tsunamis resulting from earthquakes in the Alaska-Aleutians area has now been considerably improved instrumentally with a tripartite array of seismographs that will facilitate the quick identification of the epicenters of earthquakes in the Alaskan area (Spaeth and Berkman, 1967). Whether the improvement in instrumentation has been matched by a similar attention to the propagation of the warnings resulting from the new array is not known. The Alaska Disaster Office completed a state warning plan in September 1965.

The state Office of Civil Defense was renamed the Alaska Disaster Office just after the earthquake. Before March 27, it had been in danger of losing its financial support from the legislature. The earthquake reversed that situation, at least for the time being, and the Alaska Disaster Office was strengthened in staff, communication facilities, and quarters. Its statewide disaster plan, completed in February 1965, is still nuclear-oriented but, at least at the state level, Alaska is better prepared for disaster today (Haas, 1970, this volume).

It might be expected that careful attention would be given to the design of buildings, at least in the immediate future. In all the larger cities, the existing codes already provided for appropriate earthquake-resistant construction and it is not known what additional measures have been taken since the earthquake to improve code enforcement. The Task Force did initiate a limited amount of land-use change. It recommended that certain high-risk areas should not be eligible for any type of federally supported assistance and reconstruction, and expressed the hope that such areas would serve as a basis for permanent zoning of risk areas. The original extent of such areas of risk was progressively reduced, as were restrictions on activities within them (Eckel and Schaem, 1970; Selkregg, Crittenden, and Williams, 1970, this volume). A local committee in Anchorage, known as the Engineering Geology Evaluation Group (1964), originally identified a very extensive area for permanent evacuation. The Field Committee and the Scientific Task Force subsequently identified three categories of danger area: high-risk, nominal-risk, and provisional nominal-risk (which depended on satisfactory soil stabilization). The area initially classified as high-risk was gradually reduced, strictly on scientific grounds. However, a major concession in the high-risk area was the decision to provide funds to restore buildings but not to construct new ones. Other concessions have followed, leading to a major policy change in February 1967, when FHA removed its restrictions on mortgage insurance in the two major-risk areas, requiring only the promise that mortgage lenders make clear to prospective buyers the nature of the risk and their financial responsibility in case of earthquake recurrence.

Local zoning of risk areas has not taken place. On the contrary, building permits have been issued for about $6 million worth of new construction in and adjacent to the L-K-Street-slide area.

Only one area has had its loss potential modified. In the Fourth-Avenue-slide area a gigantic earth and gravel buttress now protects (at a cost of $4 million) a major portion of the central business district. After 2 years of elaborate tests and measurements, the Turnagain-slide area has been declared stabilized by natural process. Finally, the government itself has built a warehouse near the First Avenue slide, but it also has plans to stabilize the slide in the future.

Elsewhere in Alaska (Selkregg, Crittenden, and Williams, 1970, this volume), a major evacuation effort was the relocation of Valdez at a new site 4 mi northwest and just east of the mouth of Mineral Creek. The new location had been the site of the town for a brief period in its early history. The relocation was not completed until 1968. At Seward and Kodiak, damaged sections of the waterfront were also effectively evacuated as high-risk areas. At Kodiak, the central business district was raised with fill to its former height above sea level to compensate for the subsidence that had taken place there. It is not known what measures, if any, were taken in the course of the reconstruction effort to minimize future fire hazard from earthquakes in these communities.

Substantial relocation or changes in land use were not developed at any communities other than Valdez and some of the "native villages." Urban renewal, although widely used, did not lead to substantial changes in the character of land use; however, it was important in reconstruction and stimulated some hazard-reducing action.

THE IMPACT OF THE ALASKAN EXPERIENCE ON HUMAN ADJUSTMENT TO EARTHQUAKES OUTSIDE ALASKA

The Alaska earthquake had a serious and profound effect outside the state. Literally dozens of related investigations, either to examine the experience of the earthquake itself or to reexamine earthquake hazard in other areas, were prompted by the Alaskan experience. The Department of Water Resources of the State of California, the developer of the multibillion-dollar California Water Project, was deeply concerned with the design of both earthquake-resistant structures, and of dams and aqueducts (California Department of Water Resources, 1965). The California State Resources Agency established a Committee on Geologic Hazards that has reviewed geologic hazards in California and is making recommendations for dealing with future earthquakes (Geologic Hazards Advisory Committees for Program and Organization, 1967). Richard W. Lemke has compiled a listing of some nine different types of programs related to geologic hazards, many of which were initiated or encouraged by the Alaska earthquake experience. Most of this concern, however, is within the purview of professional and technical organizations.

Some local communities have reexamined aspects of their activity. The city of Long Beach, having suffered a major earthquake in 1933, is particularly sensitive to the problem, and the Civil Defense authorities have reconsidered their own disaster plans in the light of the Alaskan experience. The city of Los Angeles reexamined its building codes and enacted new requirements for design and for instrumenting buildings. The State of California Division of Construction and Architecture restudied the lateral-force requirements and adopted a number of changes inspired by the Alaska earthquake. The division changed its rules accordingly, and pertinent changes were published in the 1967 edition of the Uniform Building Code (George Housner, telephone conversation, January 20, 1970).

In California, a public report of the State Division of Real Estate is provided to buyers or lessees in subdivisions of more than five homes. Statements are included that advise of both filled ground and earthquake hazard; the latter statement is an innovation added since the Alaska earthquake. A typical statement specifies:

> The Bureau of Mines and Geology, State of California, reports that: "This development lies within a fraction of a mile of the San Andreas fault. In the event of a strong earthquake, severe ground movement, with attendant damage to structures, might be expected."

The Alaska earthquake has initiated interest in a 10-year program for earthquake prediction and hazard reduction (Ad Hoc Interagency Working Group for Earthquake Research, 1968). It also has stimulated the development of Nationwide Natural Disaster Warning System (NADWARN), a comprehensive national detection and warning system equipped with backup communication links for providing natural-hazard warnings, both geological and climatological in character (U.S. Environmental Science Services Administration, 1965). The Committee on the Alaska Earthquake of the National Academy of Sciences reflected President Johnson's concern for the need to draw together all the scientific lessons from the Alaska earthquake.

The total expenditure for research on the Alaska earthquake from all sources may never be known because of the many federal, state, local, academic, commercial, private, and individual contributions. The lack of uniformity and definition in related costs makes the computations almost impossibly complex. Nevertheless, discussions with representatives of the three federal agencies making the largest financial contributions reveal that together, in the three years following the earthquake, they spent about $10 million for research and data collection related to that event. Therefore, an all-source total figure of around $20 million for research seems reasonable.

THE IMPACT OF THE ALASKA EARTHQUAKE ON NATIONAL DISASTER POLICY

The Alaska earthquake has had a profound effect on national disaster policy. The liberalization of sources of aid that developed out of the earthquake experience has since been extended in one form or another to victims of the Pacific Northwest floods of December 1964, Hurricane Betsy of September 1965, and the Fairbanks flood of August 1967. Another major effect of the Alaska earthquake was to turn the nation's interest again to the problems of insurance for both earthquake and other hazards.

The increased tendency to commit national resources piecemeal to alleviate the effects of disaster may or may not be appropriate, either for the best interests of social welfare or for reducing the total cost of natural hazards to the nation. The major lesson of the Alaska earthquake should be the need for a comprehensive national policy to reduce earthquake losses.

TOWARD A NATIONAL POLICY OF REDUCING EARTHQUAKE LOSSES

Before the end of this century, it is virtually certain that one or more major earthquakes will occur on the North American continent. The Alaska earthquake was exceptional in the areal extent of tectonic movement, the duration of ground motion, and the amount of energy released. In view of its great size and areal extent, the relatively small loss of life and damage to property were remarkable. Nevertheless, if one applies the per capita death rate of .00092 and per capita damage rate of $2,400 that was experienced in Seismic Zone 3 of the United States, a crude approximation of the dimensions of our earthquake problem emerges. A method suggested by Housner (a 40 percent probability in each 100 years of experiencing motion equal to or greater than that felt at Anchorage in 1964) indicates that these per capita rates of death and damage applied to a future population of 30 million in Seismic Zone 3 project 11,040 dead and $24 billion in property losses from great earthquakes over a 100-year period. With a reasonable allowance for damage from lesser events, annual damage from future great earthquakes may be estimated to average $300 million, although that figure would certainly vary greatly from year to year.

These sobering figures suggest that death and damage from earthquakes yet to be experienced in the United States will average ten times the present rate. If a single earthquake of the magnitude of the Alaska earthquake occurred in California, given the per capita rates of death and damage for the Alaskan event, it could exact a toll 20 times as great (2,000 dead and $6 billion damage).

What can we as a nation do about such a prospect? With our current understanding and technology, not a great deal. This does not mean that it may not be possible to reduce substantially the death toll. For example, we need not tolerate the erection of buildings subject to earthquake-induced collapse and on sites that are clearly unstable. The success of most buildings in Alaska in withstanding major damage despite prolonged shaking indicates that we possess the technology to design such buildings. Conversely, the failure of structures in slides or through dramatic collapse, as in the case of the Four Seasons apartment building, gives some evidence (although still debatable) of the types of design or sites to avoid.

Nor do we have to bear the inequity of natural disaster, for it is possible to find ways of sharing losses without unwittingly encouraging greater losses in the future. Although the reconstruction experience exemplifies the ability of a wealthy nation to share the burden of disaster, such experience is only partly reassuring as to the reduction of future hazard. Even a dramatic reduction in the death toll (70 percent) and a more modest reduction in the toll of damages (50 percent) would still result in a potential of 600 dead and $3 billion damage from a future great earthquake.

A realistic first principle for a program of reducing earthquake losses is that such a reduction will be modest and will be more successful in saving lives than in preventing property damage. This principle recognizes, first, that the potential of the earthquakes themselves is awesome because the amounts of energy liberated will exceed our potential for hazard control in the foreseeable future and, second, that the dispersal of population and human works into areas of high seismic potential is accelerating. We will have to labor mightily merely to keep future losses at present levels.

A second principle is that our present knowledge is inadequate and that more research is necessary. The type of research required to reduce potential earthquake losses entails priorities that do not necessarily conform to the basic-research needs in geophysics or even to thoughtfully designed earthquake-prediction programs. There is a pressing need for answers to the questions that arise from considering analogues to the Alaska experience. How would very tall buildings fare under prolonged shaking by long-period waves? Can subdivisions on natural or artificial tidal flats be safe? Can we eliminate the ambiguity in the dissemination of and response to tsunami warnings and match the progress made in the technical problem of determining whether a wave has been generated? What is a reasonable expectation for the recurrence of a major earthquake in California? How can we direct land use so as to decrease potential hazards from future earthquakes? Without minimal reasonable answers to such questions, suggestions for appropriate public policy are difficult to frame.

A third principle is that damaging earthquakes are rare events. It is neither possible nor reasonable to expect the entire population to remain lastingly alert to the hazard. Three contingent levels of activity seem to be desirable. First, there is need for persons who are professionally trained and specifically concerned with reducing potential losses. There are few such persons available today. In Alaska, for example, a highly trained person, responsible to the public, is needed to check design for seismic resistivity and to field-check construction to ensure compliance with good design standards. Second, there is need for preplanning, for providing contingency plans that can be implemented when required. Relief and reconstruction would have been improved and more rapid in Alaska had natural-disaster emergency plans been prepared, had blueprints and plans with subsequent modifications been stockpiled for rapid restoration of essential services, and had basic geologic and soil surveys been available from which to identify risk areas to be avoided in the reconstruction process (see detailed discussion, Selkregg, Crittenden, and Williams, 1970, this volume). Third, the many institutions that govern land development and human settlement need to consider the reduction of potential earthquake losses as a normal function of their customary activities. Certifying the stability of foundation material should be made part of the process of obtaining federal mortgage assistance; provision of geologic-risk maps can be made a part of the original planning procedures now required for participation in many federal urban and transportation programs. All government agencies have a responsibility to establish conditions that encourage private individuals to make conscious adjustments to earthquake hazard.

A last principle is the need for a national policy of reducing earthquake losses. The deep involvement of the federal government in Alaskan reconstruction and the potential for an even greater earthquake disaster make such a policy mandatory. This principle does not deny the urgent role of states and local communities in reducing earthquake losses. Indeed, our Constitution's division of power places much of the burden on the states and on the local communities. The Alaskan experience is, however, not very encouraging. The Scientific and Engineering Task Force provided scientific evaluations of risk of the first order for four cities and towns. The evaluations have yet to be codified into the local land-use practice of any one of the communities. Natural-disaster plans have not been developed to any degree, nor is it clear what steps have been taken to ensure better construction practices. The potential for state action differs. In a state like Alaska, with limited local resources, there is need for state leadership in providing the skilled personnel needed to certify the quality of seismic design and construction. In California, where the resources clearly exist for a major effort to reduce earthquake losses, groups have been assembled for that purpose. The critical factor in California is the attitude of the residents. Because of their unprecedented problems of growth, Californians would need some increased incentive to undertake to reduce the potential for earthquake loss in their state.

However, the case for federal initiative is persuasive. The Federal Reconstruction and Development Commission has left a legacy of thoughtful and needed recommendations, some of which have already been carried out. The U.S. Geological Survey and the Environmental Science Services Administration have been organized to focus on earthquake problems more effectively. A study of a national earthquake-insurance scheme is being conducted at the Department of Housing and Urban Development. A variety of institutional tools is potentially available to encourage local action in reducing earthquake losses; they need to be harnessed to that purpose. Finally, the burden of an earthquake disaster as envisaged in preceding paragraphs would fall on the nation, whose present fragmentary and ad hoc policy-making may be unwittingly contributing to an increase in that potential.

All the foregoing suggestions or reasons for action do not constitute a national policy. Fortunately, a clear model of how to develop such a policy exists in the form of the report of the Task Force on Federal Flood Control Policy by the Bureau of the Budget. This group was chaired by Gilbert F. White of the University of Chicago, and included senior officials of the departments of Defense; Agriculture; Interior; Housing and Urban Development; and the Tennessee Valley Authority, serving as individuals. Together with nongovernmental experts with state and national experience, the group has succeeded in assembling a *Unified National Program for Managing Flood Losses* (U.S. House of Representatives, 1966). When the program was published, President Johnson simultaneously issued an executive order putting into force a number of the recommendations of the task force. At the same time, where existing authority was available, agencies moved to implement other specific recommendations, and legislation was prepared to follow through with still other recommendations, where neither existing law nor an executive order was held to be sufficient authority. Sixteen specific recommendations were made, and satisfactory consultation was held in advance with the 19 agencies involved in flood-plain management. A clear and coherent federal initiative in this area has emerged, which extends through every related area of government. Estimated costs of a projected 10-year program for flood-plain management are $13 million a year, a figure roughly comparable to the costs of the proposed 10-year program on earthquake prediction.

This task-force approach, although most promising, will not necessarily produce as effective a policy for earthquakes as has developed for flood-plain management. Our present state of knowledge regarding flood-plain management—understanding of physical mechanisms, knowledge about human occupance, and experience with reducing damages—far exceeds that available for management of seismically sensitive areas and for reducing earthquake losses. But we do not have to repeat the 25 years of experiment in flood-plain management, in which the $7 billion dollars spent for flood-loss reduction failed to keep up with the increase in human occupance and other unforeseen aspects of human behavior. We can learn from our experience with other natural hazards while we seek also to learn from the experience of Alaska. For an affluent and responsible nation possessing great resources of wealth and talent, a reasonable goal would be to have in operation within 20 years a program of reducing earthquake losses. By that time one or more major earthquakes will almost certainly have occurred on the North American continent.

REFERENCES

Ad Hoc Interagency Working Group for Earthquake Research, 1968. Proposal for a ten-year national earthquake hazards program: A partnership of science and the community. Washington: Office of Science and Technology and the Federal Council for Science and Technology, December. 81 p.

Ad Hoc Panel on Earthquake Prediction, 1965. Earthquake prediction: A proposal for a ten-year program of research. Washington: Office of Science and Technology, September. 136 p.

Advisory Commission on Intergovernmental Relations, 1966. Building codes, a program for intergovernment reform. Washington. 103 p.

Alaska Department of Health and Welfare, 1964. Preliminary report of earthquake damage to environmental health facilities and services in Alaska [mimeographed]. Juneau: Branch of Environmental Health. 47 p.

Bartlett, E. L., 1964. Americans can be proud. *Congressional Record*, 110 (September 30), 1–8. (Also, this volume, Appendix.)

Berg, Glen V., and James L. Stratta, 1964. Anchorage and the Alaska earthquake of March 27, 1964. New York: American Iron and Steel Institute. 63 p.

Bolt, Bruce A., 1967. Jottings from Japan: the Tango, Nobi, Niigata and Matsushiro earthquakes and the Hikari train. *Bulletin of the Seismological Society of America*, 57 (February), 133–138.

Bowden, Martyn, 1967. The dynamics of city growth: An historical geography of the San Francisco Central District 1850–1931 [unpublished Ph.D. dissertation]. Berkeley: University of California.

California Department of Water Resources, 1965. The Alaskan earthquake. California Department of Water Resources Bulletin 116-5 (October), 64 p.

Coulter, Henry W., and Ralph R. Migliaccio, 1966. Effects of the earthquake of March 27, 1964, at Valdez, Alaska. U.S. Geological Survey Professional Paper 542-C. Washington: Government Printing Office. 36 p.

Cox, Doak C., 1961. Potential tsunami inundation areas in Hawaii. Honolulu: University of Hawaii Institute of Geophysics Report 14. 26 p.

Cox, Doak C., 1964. Tsunami forecasting. Honolulu: University of Hawaii Institute of Geophysics. 22 p.

Cox, Doak C., 1968. Performance of the Seismic Sea Wave Warning System, 1948–1967. Honolulu: University of Hawaii Institute of Geophysics Report HIG 68-2, March 25. 79 p.

Dacy, Douglas C., and Howard Kunreuther, 1969. The economics of natural disasters: Implications for federal policy. New York: The Free Press. 270 p.

Eckel, Edwin B., and William E. Schaem, 1970. The work of the Scientific and Engineering Task Force *in* The Great Alaska Earthquake of 1964 (Human Ecology Volume). NAS Pub. 1607. Washington: National Academy of Sciences.

Engineering Geology Evaluation Group, 1964. Geologic report: 27 March 1964 earthquake in Greater Anchorage area. Anchorage: Alaska State Housing Authority and City of Anchorage. 47 p.

Eppley, R. A., 1965 and 1966. Earthquake history of the United States. Part I, Stronger earthquakes of the United States (exclusive of California and Western Nevada). 120 p. Part II, Stronger earthquakes of California and Western Nevada. 48 p. Washington: Government Printing Office.

Geologic Hazards Advisory Committees for Program and Organization, 1967. Earthquake and geologic hazards in California: A report to the California Resources Agency, April 26. 18 p.

Grantz, Arthur, George Plafker, and Reuben Kachadoorian, 1964. Alaska's Good Friday earthquake, March 27, 1964: A preliminary geologic evaluation. U.S. Geological Survey Circular 491. Washington: U.S. Geological Survey. 35 p.

Gutenberg, B., and Charles F. Richter, 1954. Seismicity of the earth and related phenomena. Princeton: Princeton University Press. 322 p.

Haas, J. Eugene, 1970. Lessons for coping with disaster *in* The Great Alaska Earthquake of 1964 (Human Ecology Volume). NAS Pub. 1607. Washington: National Academy of Sciences.

Hansen, Wallace R., 1965. Effects of the earthquake of March 27, 1964, at Anchorage, Alaska. U.S. Geological Survey Professional Paper 542-A. Washington: Government Printing Office. 68 p.

Hansen, Wallace R., Edwin B. Eckel, William E. Schaem, Robert E. Lyle, Warren George, and Genie Chance, 1966. The Alaska earthquake, March 27, 1964: Field investigation and reconstruction effort. U.S. Geological Survey Professional Paper 541. Washington: Government Printing Office. 111 p.

Havighurst, James, 1967. Perception of tsunami hazard. Honolulu: University of Hawaii Geophysics Tsunami Research Group Recommendation No. 9. 48 p.

Healey, J. H., W. W. Rubey, D. T. Griggs, and C. B. Raleigh, 1968. The Denver earthquakes. *Science*, 161 (September 27), 1301–1310.

International Association for Earthquake Engineering, 1963. Earthquake resistant regulation. A world list. Tokyo: Association for Science Documents Information. 313 p.

Kachadoorian, Reuben, 1965. Effects of the earthquake of March 27, 1964, at Whittier, Alaska. U.S. Geological Survey Professional Paper 542-B. Washington: Government Printing Office. 21 p.

Kates, Robert W., and Gilbert F. White, 1961. Flood hazard evaluation in papers on flood problems. Chicago: University of Chicago Department of Geography Research Paper 70. p. 135–148.

Kotschnig, Walter M., 1968. Natural disasters: Agenda for action. U.S. Department of State Bulletin No. 1535, Vol. 59, p. 549–553.

Kunreuther, Howard C. 1970. Statistical studies of the post-disaster period: Damage estimates, actual expenditures, and sources of financial aid *in* The Great Alaska Earthquake of 1964 (Human Ecology Volume). NAS Pub. 1607. Washington: National Academy of Sciences.

Lantis, Margaret, 1970. Impact of the earthquake on health and mortality *in* The Great Alaska Earthquake of 1964 (Human Ecology Volume). NAS Pub. 1607. Washington: National Academy of Sciences.

Larrabee, Eric, 1964. Letter from Skopje. *The New Yorker*, 40 (October 17), 131-184.

Lemke, Richard W., 1967. Effects of the earthquake of March 27, 1964, at Seward, Alaska. U.S. Geological Survey Professional Paper 542-E. Washington: Government Printing Office. 43 p.

McMinn, Jack H., 1964. The verdict of Anchorage: Good structural design survived. *Engineering News-Record*, 172 (April 9), 22–25.

Medvedev, S. V., 1965. Engineering seismology [Translated from Russian edition of 1962]. Jerusalem: Israel Program for Scientific Translations. 260 p.

Miller, Robert D., and Ernest Dobrovolny, 1959. Surficial geology of Anchorage and vicinity, Alaska. U.S. Geological Survey Bulletin 1093. Washington: Government Printing Office. 128 p.

National Board of Fire Underwriters and Pacific Fire Rating Bureau, 1964. The Alaska earthquake, March 27, 1964. San Francisco: American Insurance Association. 35 p.

New Zealand Official Year Book, 1965. Wellington [New Zealand]: Department of Statistics.

Niddrie, David Lawrence, 1961. When the earth shook. London: Hollis and Carter. 190 p.

Norton, Frank R. B., and J. Eugene Haas, 1970. The human response in selected communities *in* The Great Alaska Earthquake of 1964 (Human Ecology Volume). NAS Pub. 1607. Washington: National Academy of Sciences.

Press, Frank, and David Jackson, 1965. Alaskan earthquake, 27 March 64: Vertical extent of faulting and elastic strain energy release. *Science*, 147 (February 19), 867–868.

Rogers, George W., 1962. The future of Alaska: Economic consequences of statehood. Baltimore: Johns Hopkins Press. 311 p.

Rogers, George W., 1970a. Economic effects of the earthquake *in* The Great Alaska Earthquake of 1964 (Human Ecology Volume). NAS Pub. 1607. Washington: National Academy of Sciences.

Rogers, George W., 1970b. Basic population and employment statistics, south central Alaska, 1960–1967 *in* The Great Alaska Earthquake of 1964 (Human Ecology Volume). NAS Pub. 1607. Washington: National Academy of Sciences.

Rogers, George W., 1970c. Impact of the earthquake on the economy of Alaska *in* The Great Alaska Earthquake of 1964 (Human Ecology Volume). NAS Pub. 1607. Washington: National Academy of Sciences.

Selkregg, Lidia, Edwin B. Crittenden, and Norman Williams, Jr., 1970. Urban planning in the reconstruction *in* The Great Alaska Earthquake of 1964 (Human Ecology Volume). NAS Pub. 1607. Washington: National Academy of Sciences.

Shannon and Wilson, Inc., 1964a. Preliminary report to U.S. Army Corps of Engineers on Fourth Avenue slide, Anchorage, Alaska. Seattle. 10 p.

Shannon and Wilson, Inc., 1964b. Preliminary report to U.S. Army Corps of Engineers on Turnagain slide, Anchorage, Alaska. Seattle. 10 p.

Shannon and Wilson, Inc., 1964c. Report on subsurface investigation for city of Seward, Alaska, and vicinity, to U.S. Army Engineer District, Alaska, August 28. Seattle. 77 p.

Shannon and Wilson, Inc., 1964d. Report on Anchorage area soil studies, Alaska, to U.S. Army Engineer District, Alaska, August 28. Seattle. 300 p.

Shannon and Wilson, Inc., 1964e. Report on subsurface investigation for Mineral Creek townsite, city of Valdez, Alaska, to U.S. Army Engineer District, Anchorage, Alaska. Seattle. 34 p.

Spaeth, Mark G., and Saul C. Berkman, 1967. The tsunami of March 28, 1964, as recorded at tide stations. U.S. Coast and Geodetic Survey Technical Bulletin No. 33. Washington: Government Printing Office. 86 p.

Stepp, J. Carl, 1966. Seismic probability maps *in* ESSA symposium on earthquake prediction. Washington: Environmental Science Services Administration. p. 106-109.

United Nations Centre for Housing, Building and Planning, 1966. Report on the rehabilitation and reconstruction of housing and community facilities in cases of natural disasters, Part II. New York: United Nations Economic and Social Council, Committee on Housing, Building and Planning Publication E/C, v. 6, May 25. 73 p.

U.S. Coast and Geodetic Survey, 1965. Tsunami! The story of the Seismic Sea-Wave Warning System. Washington: Government Printing Office. 46 p.

U.S. Environmental Science Services Administration, 1965. A proposed nationwide natural disaster warning system (NADWARN). Washington. 113 p.

U.S. House of Representatives, 1966. A unified national program for managing flood losses. House Document 465, 89th Congress, second session. Washington: Government Printing Office. 47 p.

Waller, Roger M., 1966a. Effects of the earthquake of March 27, 1964, in the Homer area, Alaska. U.S. Geological Survey Professional Paper 542-D. Washington: Government Printing Office. 28 p.

Waller, Roger M., 1966b. Effects of the March 1964 Alaska earthquake on the hydrology of south-central Alaska. U.S. Professional Paper 544-A. Washington: Government Printing Office. 28 p. (Also, Hydrology Volume, p. 12–39.)

Waller, Roger M., 1966c. Effects of the March 1964 Alaska earthquake on the hydrology of the Anchorage area. U.S. Geological Survey Professional Paper 544-B. Washington: Government Printing Office. 18 p. (Also, Hydrology Volume, p. 82–96.)

White, Gilbert F., 1964. The choice of adjustment to floods. Chicago: University of Chicago Department of Geography Research Paper 93. 149 p.

White, W. R. H., 1966. The Alaska earthquake–its effect in Canada. *Canadian Geographical Journal,* 72 (June), 210–219.

Wilson, Martha, 1964. Public Health Notes. Anchorage: Alaska Native Service Hospital. p. 853.

Yutzy, Daniel, and J. Eugene Haas, 1970. Disaster and functional priorities in Anchorage *in* The Great Alaska Earthquake of 1964 (Human Ecology Volume). NAS Pub. 1607. Washington: National Academy of Sciences.