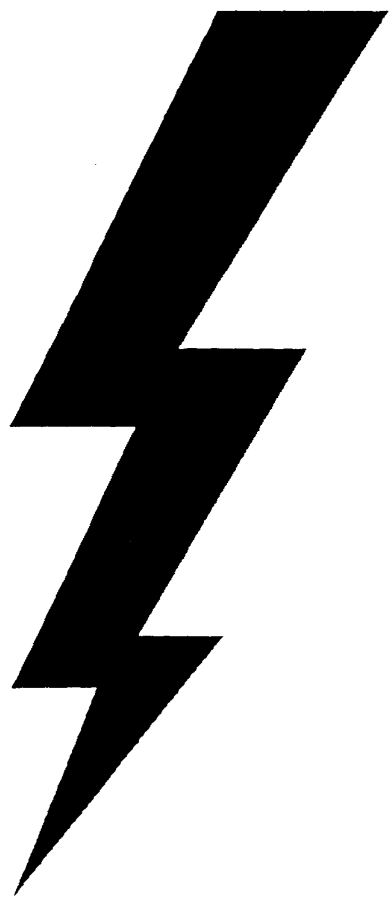
ENVIRONMENTAL CATASTROPHE PROJECT

PROJECT REPORT



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for
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ENVIRONMENTAL CATASTROPHE PROJECT

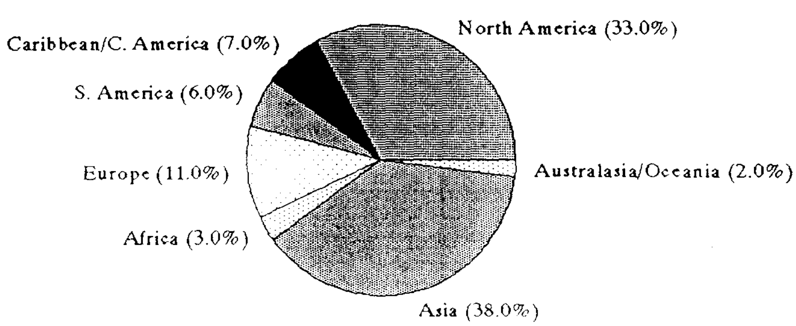
PART ONE – THE HAZARDS

I N T R O D U C T I O N

In the late 1970s, it was estimated that natural hazards cost the global economy at least $40 billion per year, with some $25 billion in loss and $15 billion spent on mitigation. In an average year it was claimed that such events killed around 250,000 people.

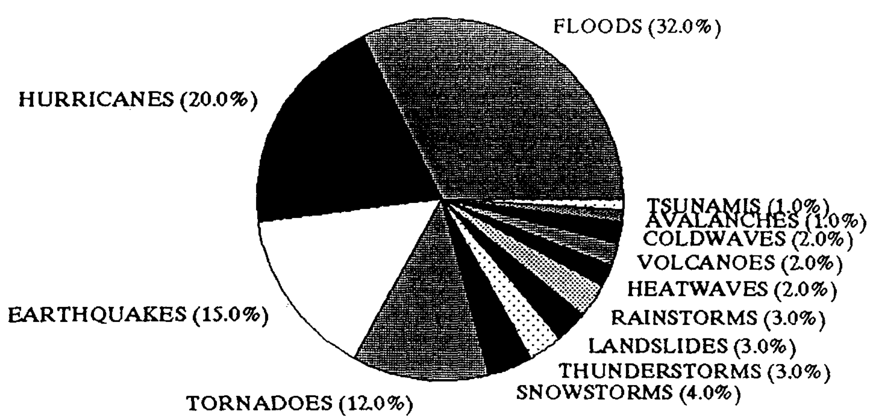
The scale of physical destruction, and the quantifiable economic consequences, of disaster are great. The estimates for the cost of 1992's Hurricane Andrew range between $15–16.5 billion. Estimates of the damage caused by storm–force winds in southern England in October 1987 indicate agricultural costs of £40 million. About one British house in six suffered some structural damage and insurance claims for all property sectors reached £1 billion to £2 billion.

Proportional incidence of disasters by continental areas, 1947–1981



Disaster impact not only varies greatly from year to year, from hazard to hazard, and in the type of loss, but it also varies spatially across the globe.The explanation of such variability lies in both the physical characteristics and the social vulnerability of different regions. The nature of the physical environment ensures that certain hazards are specific to different parts of the globe. For example, major earthquakes are largely confined to the margins of lithospheric plates, river floods to flood plains and tropical cyclones to coastal zones in relatively low latitudes. Thus, Asia tends to suffer disproportionately from natural disasters because much of the continent is densely populated and lies in tectonically active zones or near low–lying tropical coasts subject to cyclones.

GLOBAL DISASTERS BY TYPE 1947–81



Most of the economic loss from environmental hazard, however, occurs in the developed world. Existing estimates for the United States place the total annual losses from all natural hazards somewhere between $5 billion and $10 billion.

DISASTER TRENDS

Risk patterns can change appreciably over time. However, any evidence must be interpreted cautiously because changes can be complex. In the West Indies, for example, the exposed risk has changed for different hazards as the area has developed. Whilst continuing waterfront development has increased the hazard from storm surge and tsunami, the increased use of masonry in house construction has lowered the threat from hurricane winds, although such properties have an increased vulnerability to earthquakes.

Another problem is that continuous improvements in monitoring systems and global communications will tend to produce a progressive, but artificial, increase in frequency of disaster detection. Bearing these limitations in mind, recent decades have provided evidence of increased disaster impact. Based on insurance data, natural disasters have shown an approximate five–fold increase in frequency from the 1960s to the 1980s (Berz, 1990). On average, total economic losses have grown by a factor of 3.3 and total insured losses have grown by a factor of 5.8. In view of improved communications and growing hazard awareness, these values may over–estimate the real position but the changes are sufficiently large to suggest that a genuine increase is taking place in disaster impact.

With respect to noticeable disaster trends, property losses are highly sensitive to individual hazard events to the extent that, in the case of hurricanes, total damage actually declined in the 1980s due to the $7.6 billion in damages caused in the previous decade by hurricane "Agnes" in 1972. However, if damage for hurricanes and tornadoes is plotted as a function of incidence of events, and allowance is made for the cost of "Agnes", the economic losses are still rising There are several reasons why the world trend is probably towards more disaster–related deaths and damages. We shall be concentrating on economic costs rather than disaster–related deaths.

LAND PRESSURE Countries with a legacy of deforestation, soil–erosion and over–cultivation find their environment more vulnerable to environmental hazard, especially floods and droughts. In many countries the impoverishment of the agricultural base has led to large shifts of population from rural areas to urban centres. This acts to concentrate risk.

ECONOMIC GROWTH Continued economic growth in developed countries over recent decades has increased the exposure to catastrophic property damage. Along with the growing complexity and cost of the physical plant responsible for the world's industrial output, capital development has ensured that each hazard will encounter an increasing amount of property unless steps are taken to reduce the risks within cities. Partly in response to the growing shortage of building land, much of the growth has occured in areas subject to natural hazards whilst man–made hazards such as toxic chemicals and the use of nuclear power have added to the loss potential. The avilability of increased leisure time has led to the construction of many second homes built in potentially dangerous locations such as mountain and sea–shore environments.

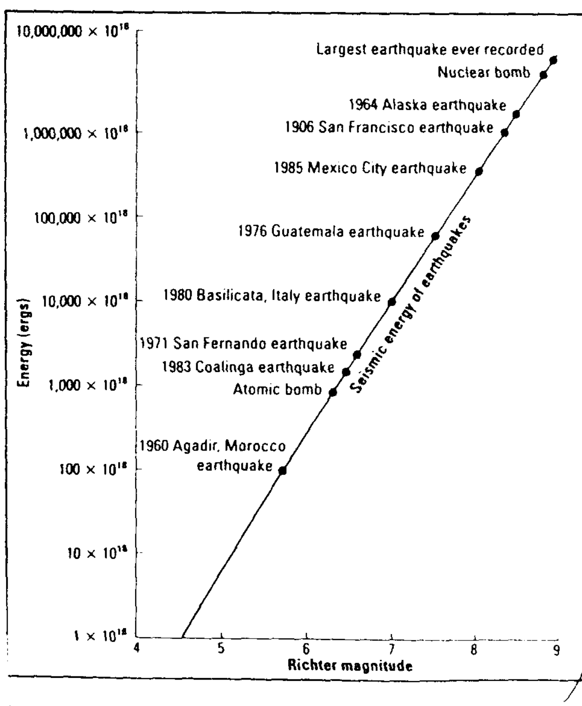
TECHNOLOGICAL INNOVATION The rising technology of the developed world is normally seen as helping to prevent disaster through better forecasting systems or safe construction techniques. However, as society becomes dependent on advanced technology, the greater is the potential for disaster if technology fails. Normally reliable systems cannot be guaranteed to resist environmental stresses and other factors increase the risk. Continued urbanisation, new high-rise buildings, large dams, building construction on man-made islands in coastal areas, the proliferation of nuclear reactors, the reliance on mobile homes for low-cost housing, more expensive transportation (especially air-travel) are all examples of technological and social trends which create increased vulnerability to hazard.

ADJUSTMENT TO HAZARD – REDUCING LOSS

Loss Reduction can be achieved in one of two principal ways: either by modifying the hazard event itself or by reducing its human impact.

EVENT MODIFICATION: ENVIRONMENTAL CONTROL

Event modification is limited as a response by the minor degree of control which humans can exert of the destructive forces of nature. Most geophysical hazards, fro example, employ releases of energy that are far beyond the capability of human control. In a single day, the atmosphere receives enough solar energy to generate 10,000 hurricanes, 100 million thunderstorms or 100 billion tornadoes. Expressed relative to this energy receipt (taking the global solar energy received in one day as 1), a strong earthquake would release 10^{-2} units, an average cyclone 10^{-3} units. Compared to this, the detonation of the Nagasaki bomb in 1945 released only 10^{-8} units whilst the street lighting on an average night in New York City involves 10^{-11} units.



For seismic hazards, such as volcanoes, earthquakes and tsunamis, there are no known methods of supression or control. Human interference with crustal rocks, for example, through weight loading from water reservoirs or increased geological pressure arising from the disposal of liquid waste may be sufficient to trigger man–made earthquakes. Similar uncertainties about feedback mechanisms affecting dynamic processes in the atmosphere make it equally difficult to control the underlying causes of climactic and hydrologic hazards.

Despite these problems, attempts have been made to modify some atmospherically derived hazards such as hurricanes, hail, avalanches and floods. In the case of hurricanes and hail, cloud seeding techniques have been employed to reduce the wind velocity and the size of the ice–particles respectively. Controversy surrounds cloud seeding, partly because the benefits are rarely clear–cut, but also because of fears that other interdependent processes (like rainfall) will also be affected. Weather modifications on this scale cannot be guaranteed to remain in the area of treatment and some effects could extend well beyond the area where hazard supression was intended. In addition, the usual seeding agents, such as silver iodide, are recognised pollutants.

EVENT MODIFICATION: HAZARD–RESISTANCE

This involves the protection of relatively small areas or individual sites by the application of specific design measures. In many countries, important public facilities such as dams, bridges and pipelines are likely to be hazard–resistant because they will have been designed by professional engineers to withstand environmental stress dueing their expected lifetime. The same is true for sensitive structures such as nuclear power plants and chemical factories.

In the case of earthquakes, hazard resistance begins with geotechnical engineers who apply the principles of rock and soil mechanics to the safe design of earth and earth–supported structures. Other things being equal, buildings on solid rock are less likely to suffer damage than those built on clays or softer foundations.

All properly engineered buildings are designed according to local building codes which tend to undergo continuous improvement. The development of improved building codes, their adoption and enforcement is the primary means of transferring engineering research findings to increase hazard resistance of structures.

Today, virtually all building damage and failure under earthquake or other hazard stresses can be technically explained with existing knowledge. This is not to say that engineered structures will never fail. Codes rarely estimate the maximum possible loads which may occur. Rather they provide for design against the intensity of hazard event which is considered to have a reasonable chance of occurring during the lifetime of the structure.

The physical advantages of hazard–resistant design are comparitively well known but the method has had rather limited application in the past. One reason for this has been the priority given to functional requirements of buildings during disaster events. Most attention has been paid to public buildings and facilities which are expected to remain operative during emergencies (hospitals, police stations, safety organisations, lifelines) and those which are expected to remain intact in order to house essential items. Other public buildings, such as schools, offices and factories have sometimes been strengthened in the belief that they will shelter large numbers of people. Occasionally, government premises have been exempted from building codes but most hazard damage is suffered in the residential and private sector.

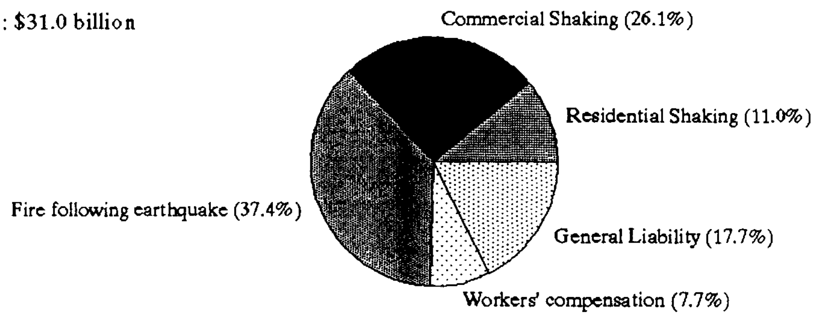
RETROFITTING Another obvious limitation exists if hazard–resistant design is restricted to new properties. Because of this, retrofitting has enjoyed increased attanetion. This is the act of modifying an existing building to protect it, or its contents, from a damaging event. A particular attraction of retrofitting hazard–resistant features is that most of the construction and maintenance cost is borne by the property–owner rather than the government. However, little research has been undertaken on the efficacy of retrofitting and little official encouragement has been given to this strategy.

SEISMIC HAZARDS: EARTHQUAKES

Earthquakes are the main seismic hazard. They affect at least 35 countries and kill directly more people per year, on average, than any other hazard.

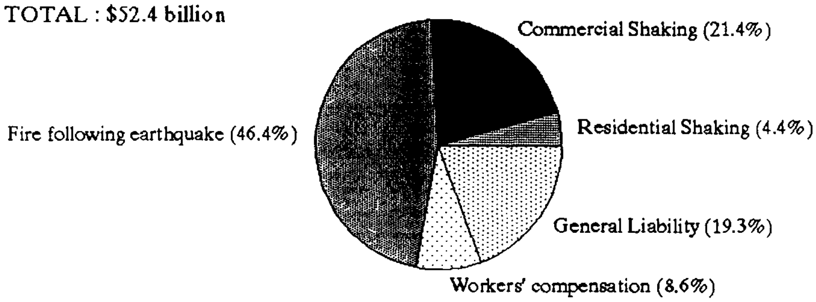
EST. INSURANCE INDUSTRY LOSS FOR NORTHERN SAN ANDREAS FAULT, CALIFORNIA

TOTAL : $31.0 billion



EST. INSURANCE LOSS FOR NEWPORT–INGLEWOOD FAULT, CALIFORNIA

TOTAL : $52.4 billion



A catastrophic earthquake is probably the greatest natural hazard faced by the USA with an estimated 70 million Americans exposed to severe risk and an additional 120 million exposed to moderate risk (Lecomte, 1989). There is a real possibility that the US might experience a major earthquake within the period 1990–2010 with costs exeeding $100 billion. It is doubtful if the private insurance industry has either the capacity to make available all the cover which might be sought against this scale of disaster or has the reserves to meet the claims that would ensue. Even the relatively modest Loma Prieta earthquake (magnitude 7.1), which struck San Francisco in October 1989, left 62 dead, with some 13,000 homeless and damage variously estimated at $10 billion.

The vast majority of the exposed risk from earthquakes is presently uninsured, even in those countries where government–supported schemes have been introduced. Most policies are on commercial and industrial property rather than residential property. In the San Fernando, California, earthquake of 1971 property damage amounted to some $500 million, of which only $32 million was covered by insurance (Hudson and Petak, 1981). Since the subsequent disaster loan programme provided over $257 million in aid, it is evident that the general tax–payer assumes much of the financial burden.

EARTHQUAKE HAZARDS

One of the worst geophysical hazards ever recorded was the Shensi, China, earthquake of 1536, with over 800,000 deaths. This phenomenal loss of life was due to the fact that the victims were living in caves in unstable hillsides and illustrates the important role played by housing in all earthquake disasters.

In urban areas, fire is the important cause of diaster. More than 80% of the total property damage in the San Francisco earthquake of 1906 was due to fire rather than to the ground shaking (ironically, the fire was caused by a woman cooking on a damaged gas stove, some four hours after the earthquake). Similarly, in the 1989 event, the failure of gas pipes and water pipes led to fires within the city.

During the Tokyo earthquake of 1923, while only about one percent of buildings were severely damaged by shaking, enuing fires destroyed two–thirds of the city, some 300,000 buildings. But whilst cities are being built with less and less wood, the trend towards the use of new plastics in architecture may well increase fire risk again.

Oil refineries and gas and petroleum storage tanks are a relatively new source of fire hazard – the whole industrial area of Seward, Alaska was destroyed in 1964, including railyards, powerplant and 26 giant petroleum tanks.

Another earthquake–related hazard is that of dam collapse. There has yet to be a major disaster although a number of small dams have collapsed in earthquakes. In the San Fernando earthquake of 1971, in a suburb of Los Angeles, the Lower Van Norman earth–fill dam came within a fraction of disaster as the crest of one half of the dam slipped into the reservoir. The water was prevented from overspilling only by a thin sliver of earth on the dam's outer edge. If the water had been a yard higher, or the shaking had continued for a few more seconds the dam would hav e collapsed, flooding 80,000 people downstream in the San Fernando Valley. There are 226 dams in the San Francisco region with over half a million people living downstream from them, however it is thought that only the older dams are a genuine hazard.

D I S T R I B U T I O N

The regional distribution of earthquakes is far from random. About two–thirds of all large earthquakes are located in the so–called "Ring of Fire" around the Pacific which, in turn, is closely related to the geophysical activity associated with plate tectonics. Seismologists have established that plate boundaries fall into two broad types, zones where the plates are separating and those where the plates are colliding. However, though around 95% of earthquakes occur along plate boundaries, a few, known as intraplate earthquakes, occur in the middle of plates. The largest earthquake in the past two centuries in the continental USA was not, as might be supposed in California, but far from a plate boundary in almost uninhabited New Madrid area of Missouri in the winter of 1811–12 .

Such rogue intraplate earthquakes reveal that the plate interiors are not completely rigid. Plate boundaries in the continents are where movement is taking place today, and the zone of this movement itself changes with time.
Like a Rubik's cube, a region at one period may be firmly bonded to the next, and then the boundary between the two becomes the site of movement.Large areas of the continents – much of Europe and North America – are riddled with old fault zones which were part of plate boundaries, and formerly as seismically active as California. Research has yet to reveal why earthquakes such as in New Madrid, and in Charleston, South Carolina in 1886, happened where they did. According to a leading earthquake consultant (Wood, 1986) : "If one thing is almost certain it is that the next intraplate earthquake in North America will occur somewhere else...And somewhere in the next few decades, there will be a significant rogue intraplate earthquake in the midst of the industrial nations of Europe, North America or Australia, *where it will be least expected"*.

Major earthquakes often last for much less than a minute and there has been great difficulty in estimating their scale and hazard impact accurately. Two common methods exist; one for *magnitude* and one for *intensity* (though magnitude is now tending to become displaced by a new measure of earthquake size, independent of the instrument used, the type of wave studied, or the ground beneath the instrument, known as the Moment Scale, which is a "true measure of energy released".

Magnitude is normally assessed on the Richter Scale. This is a complex logarithmic scale measuring the vibrational energy of the shock. Every time the magnitude is raised by one unit, the amplitude of the seismic waves increases ten–fold. Thus, an earthquake measuring 10.6 on the Richter Scale would release 1 million times more energy than a 4.3 magnitude earthquake. Though the scale has no theoretical upper limit, it is thought that rocks would shatter before building up sufficient energy to release a magnitude 10 event and very few earthquakes larger than 9 have ever been recorded. Empirical evidence suggests that most shallow earthquakes need to attain a magnitude of at least 5.5 before a major disaster occurs.

Energy release and Richter magnitude can be a poor guide to the hazard impact, which also depends on factors such as the distance from the epicentre to the damage area, rock and soil conditions, population density and the nature of building construction. Duration of ground–shaking, for example, is not accounted for in the magnitude concept. A series of small earthquakes may be as damaging as one large event, especially if after–shocks continue to attack weakened buildings.

Intensity is the only measure of ground–shaking from earthquakes that correlate directly with damage to ordinary structures. The Modified Mercalli Intensity Scale is most commonly used to rate Intensity (See Appendix 1,)

Earthquakes are caused by sudden movements along a geological fault in rocks comparatively close to the earth's surface. Most movements are preceded by the slow build–up of tectonic strain which progressively deforms the crustal rocks and produces stored elastic energy. When the imposed stresses exceed the strength of rock, it fractures, usually along a line of pre–existing weakness known as a fault. This sudden rupture releases the stored strain energy and produces seismic waves which radiate outwards in ever–widening circles. It is the fracture of stressed rocks, followed by elastic rebounding on either side of the fracture to a less strained position, which is the cause of ground–shaking.

The point of rupture, known as the focus, can occur anywhere between the earth's surface and a depth of 600–700km. Shallow–focus earthquakes (<40km below the surface) are the most damaging events, accounting for about three–quarters of the global seismic energy release. For example, the

San Fernando, California, earthquake of 1971 had only moderate magnitude (6.4 on the Richter Scale) but, because it occurred only 13km below the surface much damage was created. The source point for earthquake measurement is the epicenter, which lies on the earth's surface directly above the focus.

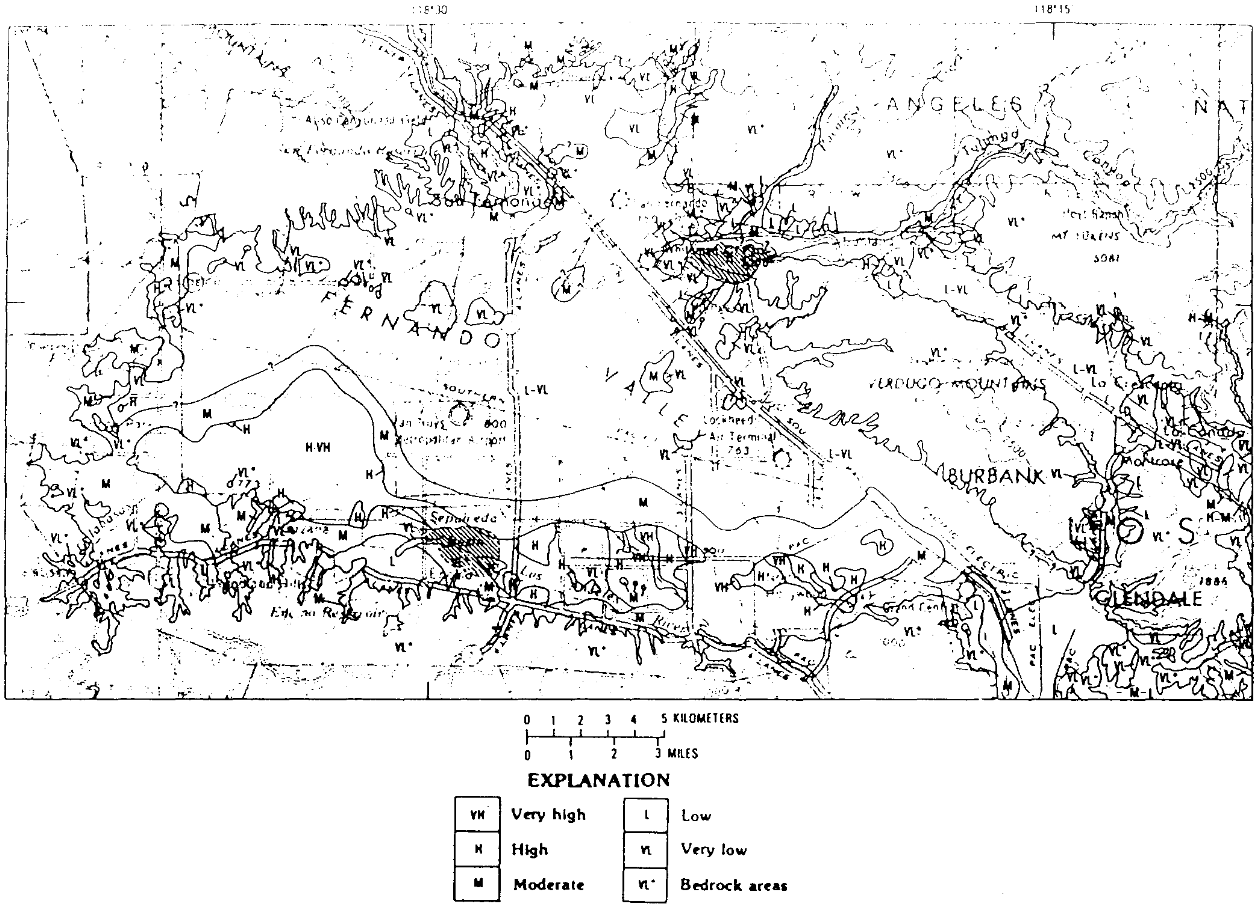
SECONDARY EARTHQUAKE HAZARDS Secondary earthquake hazards include soil liquefaction, landslides, rock and snow avalanches, tsunamis and seiches.

One of the most serious hazards associated with soft sediments is soil liquefaction. This is the process by which water–saturated sediments temporarily lose strength, usually because of strong shaking, and behave as a fluid. Liquefaction–related ground failure has created great losses. In the 1964 Alaska earthquake, the sandy soil of the Turngain Heights area of Anchorage liquified to produce a flow some 2km long and 30m wide which dislodged more than 70 buildings. Most of the damage and loss of life in the 1989 San Francisco earthquake occurred on reclaimed land underlain by clay in the Bay area.

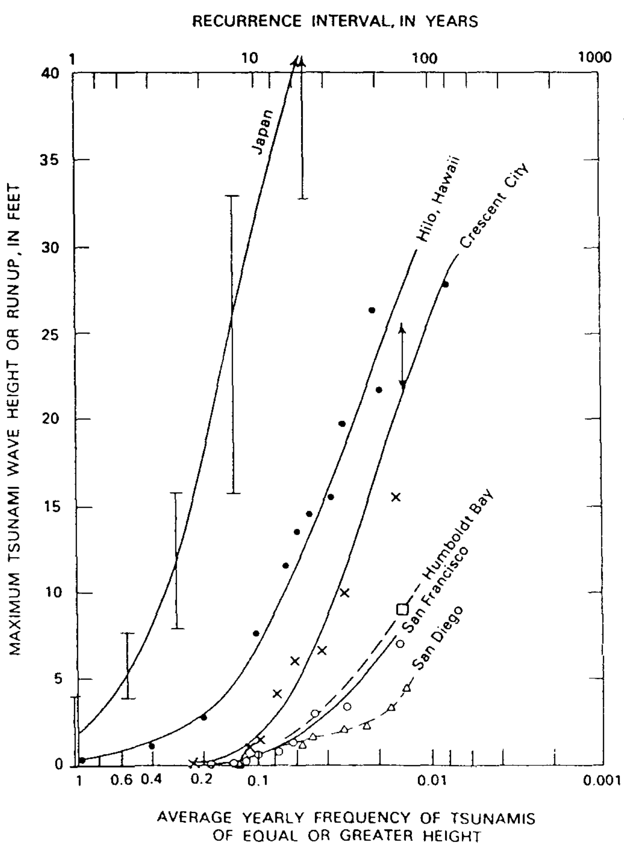
The severe shaking in an earthquake can cause natural slopes to weaken. The resulting landslides, rock and snow avalanches are major contributors to earthquake disasters, largely because so many destructive earthquakes occur within mountainous regions. In a study of large magnitude (>6.9) Japanese earthquakes since 1964, more than half of all earthquake–related deaths were caused by landslides.

The most characteristic secondary earthquake–related hazard is the seismic sea wave or tsunami. The word "tsunami" comes from two Japanese words, *tsu* meaning port or harbour and *nami* meaning wave or sea. Most tsunamis result from tectonic displacement of the sea bed, associated with large, shallow–focus earthquakes under the oceans but they can also be caused by exploding volcanic islands (eg Krakatoa in 1883). Tsunamis pose a threat to 22 countries in the circum–Pacific region. The most active source region was along the Japan–Taiwan island arc where over one quarter of all events since 1900 were generated.

During the twentieth century, some $500 million in property damage was caused by US tsunamis. The greatest losses were sustained from the 1964 Alaska tsunamigenic earthquake. Crescent City, California, suffered $7



Relative liquefaction susceptibility in the San Fernando Valley based on 1944 ground-water data Relative susceptibility to liquefaction-related ground failure is interpreted as a function of the age of the saturated materials and the depth to ground water. VH designates areas likely to contain very young, relatively well sorted stream-channel and levee deposits where the depth to ground water is less than 10 ft.



Comparison of maximum height or runu with frequency and recurrence interval for tsunami waves in Japan, California, and Hawaii.

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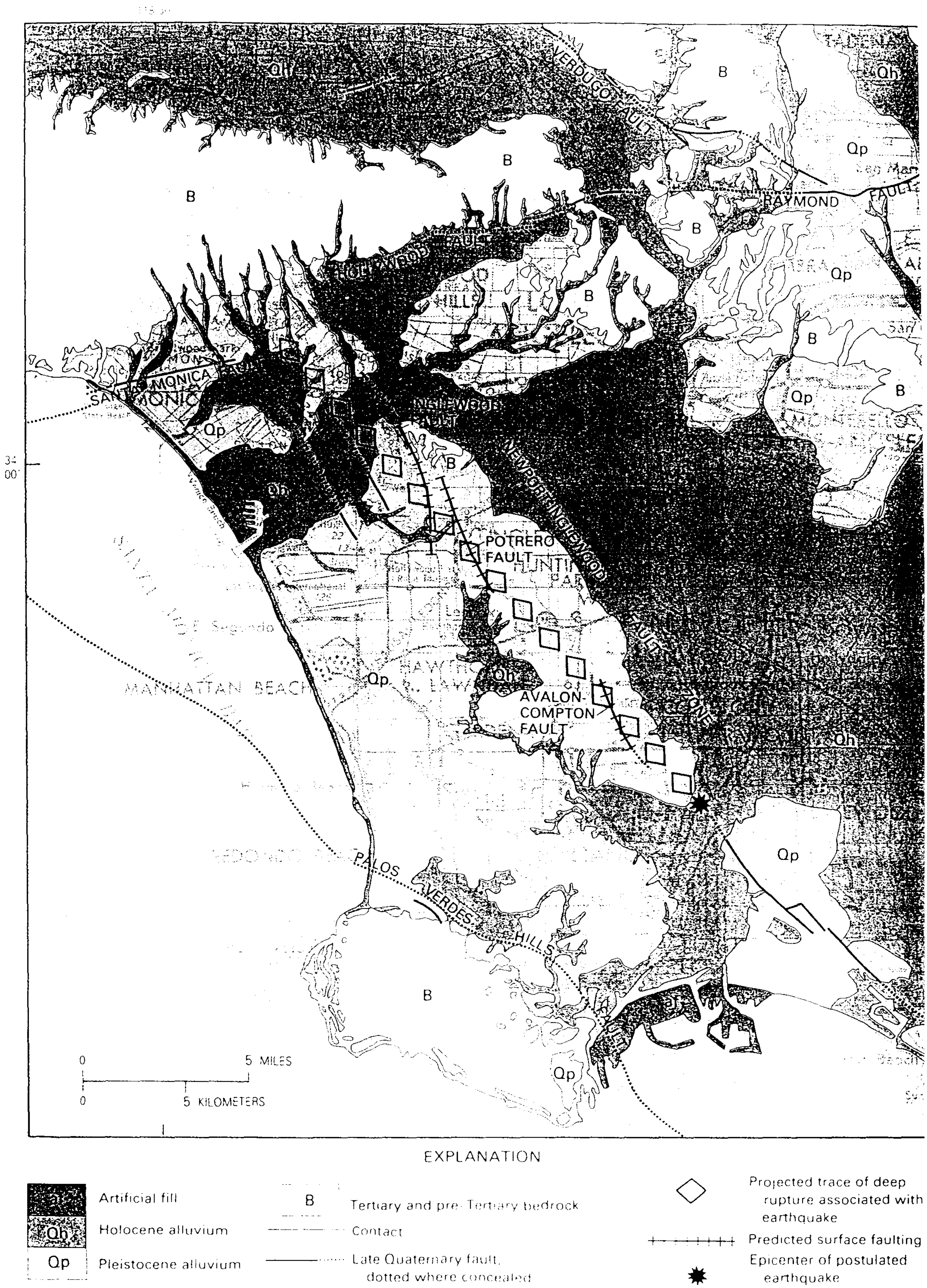

VERDUGO FAULT
RAYMOND
FAULT
HOLLYWOOD FAULT
SANTA MONICA FAULT
INGLEWOOD FAULT
NEWPORT-INGLEWOOD FAULT ZONE
POTRERO FAULT
AVALON-COMPTON FAULT
MANHATTAN BEACH
PALOS VERDES HILLS
B
Qp
Qh
34
00'
0
5 MILES
0
5 KILOMETERS
EXPLANATION
Artificial fill
Qh
Holocene alluvium
Qp
Pleistocene alluvium
B
Tertiary and pre-Tertiary bedrock
Contact
Late Quaternary fault, dotted where concealed
Projected trace of deep rupture associated with earthquake
Predicted surface faulting
Epicenter of postulated earthquake

million damage associated with a wave 6m above low tide level which penetrated over 500m inland, flooding about 30 city blocks and destroying most of the waterfront buildings.

Seiches are much smaller water waves created in lakes and reservoirs, usually at some distance from the earthquake source. These long period movements can cause a hazard if water spills, for example over the dam of a storage reservoir, and creates a flood. Other earthquake–related floods occur when ground–shaking or landslides create dam–failures.

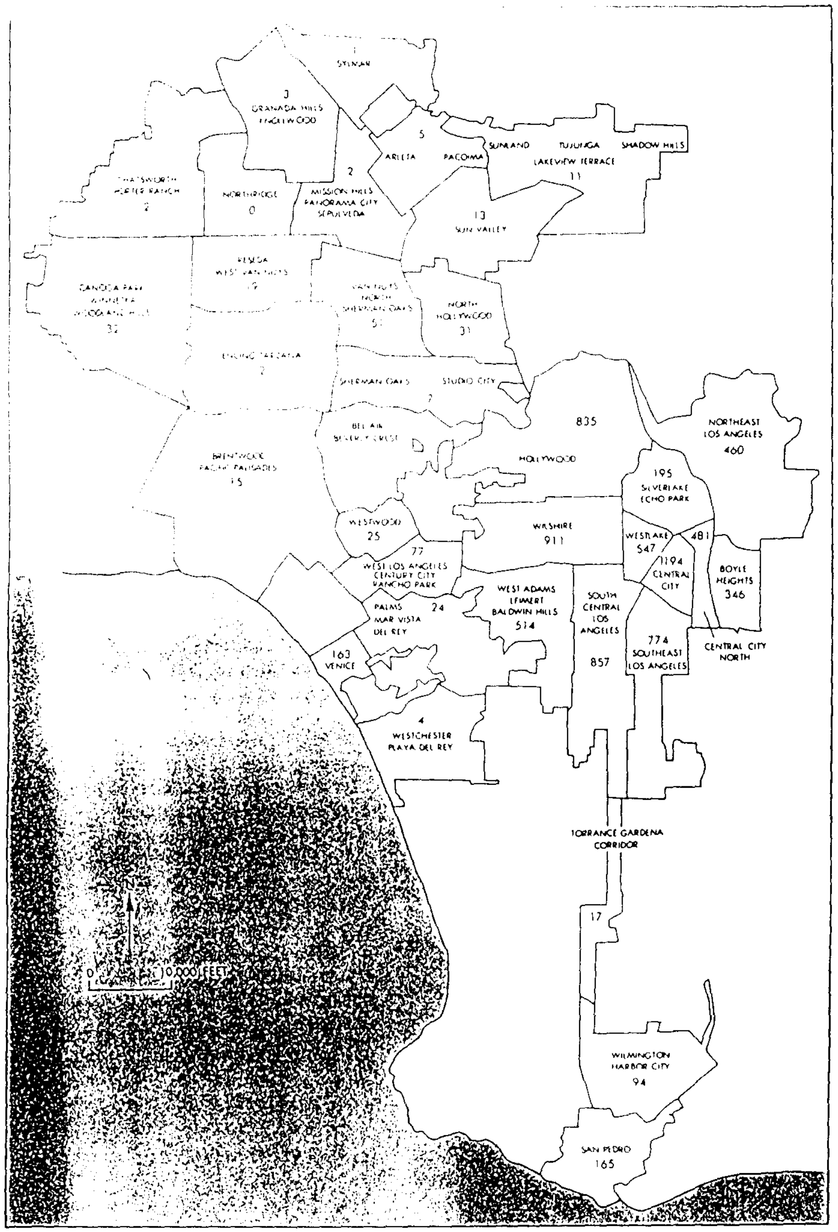
EVENT MODIFICATION : ENVIRONMENTAL CONTROL

At the present time, there appears to be little prospect of humans being able to supress earthquakes. Therefore, the most effective adjustment would involve the deliberate inducement of small–scale seismicity in order to prevent the accumulation of potentially damaging strain energy. There are well–documented cases of man–made reservoirs inducing relatively small events. It is thought that the extra load of water on the earth's crust is sufficient to trigger shallow earthquakes along sensitive fault–lines. The effect was first observed with the creation of Lake Mead on the Colorado River in 1935. However, in other tectonically active areas the construction of large dams has not led to more earthquakes. Another possibility exists in the manipulation of groundwater levels.

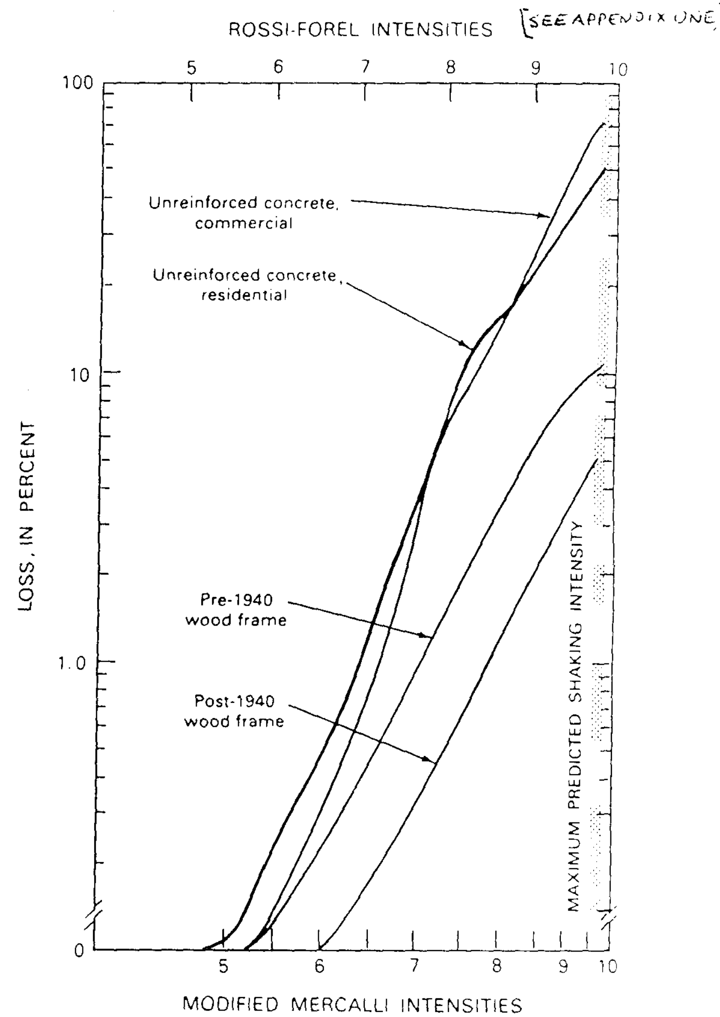
The idea of pumping water down deep boreholes along the San Andreas Fault was once considered. However, encouraging faults to move to induce small earthquakes instead of a future, large earthquake was shown to be in the realms of science fiction. The boreholes (some 5–15km deep) would have been costly and, since the magnitude scale is logarithmic, a typical San Francisco earthquake of magnitude 8 would have required the controlled release of almost 3 million magnitude 4 earthquakes.

EVENT MODIFICATION: HAZARD–RESISTANT DESIGN

There is an old saying to the effect that it is buildings, not earthquakes that kill people. The vast majority of earthquake–related deaths, and most of the financial loss, is due to the structural collapse of houses and other buildings. The actual impact is greatly influenced by building materials and methods. For example, architectural style can contribute to disaster if features like chimneys, parapets, balconies and decorative stonework are inadequately secured.



The number of unreinforced masonry buildings originally verified in the field for each census tract by the Los Angeles Department of Building and Safety (Los Angeles City Planning Department, 1979) are shown here by community area. Similar diagrams are available showing the number of dwelling units in apartment buildings or the number of guest rooms in hotels and motels. Unnumbered areas are outside the city's corporate limits.



–Percent loss from shaking versus intensity versus various types of structures (data from Evernden and others, 1981; Gulliver, in press).

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If one could start from scratch and rebuild cities with unlimited resources, perhaps as much as 90% of the death and damage from earthquakes could be avoided. Clearly this is impossible and retrofitting safety into existing buildings remains the most important strategy. The vast majority of buiding stock predates state–of–the–art design standards. For example, California alone has about 60,000 unreinforced masonry buildings which were constructed before 1933 and are now deemed to be unsafe in an earthquake. The Unreinforced Masonry Law passed by the state legislature in 1986 required all cities and counties in Seismic Zone 4, which includes most of the metropolitan areas in California, to identify such buildings by 1 January 1990.

Without effective enforcement, building codes are worthless. The benefits of hazard–resistant design were illustrated in the Loma Prieta earthquake of 1989 when very few buildings collapsed. The major casualty was the upper deck of a San Francisco freeway built in 1957 to outdated standards.

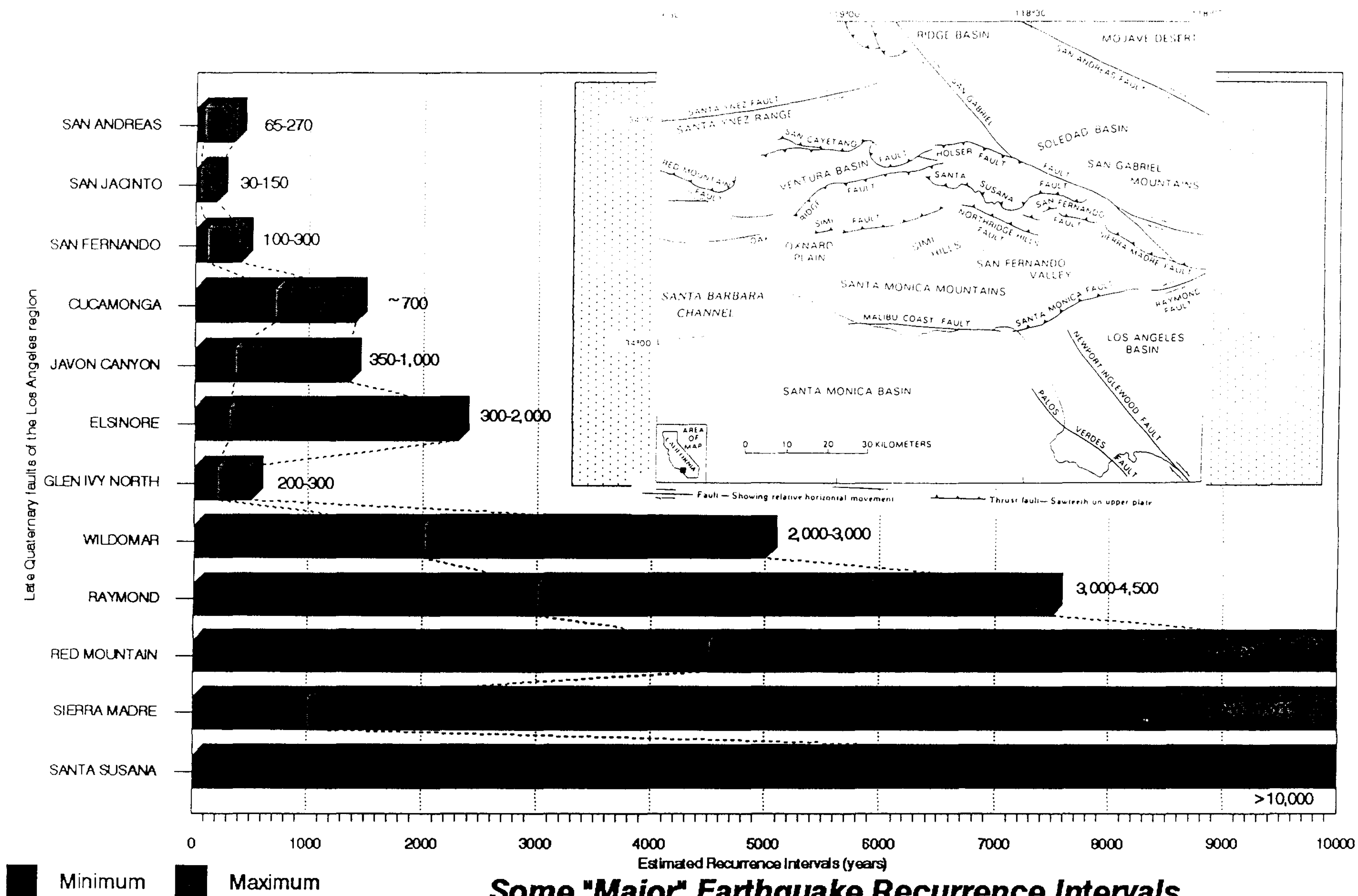
Defensive engineering works can offer some protection against tsunamis and the Japanese government has since 1960 subsidised the construction of breakwaters by up to 80%.

FORECASTING

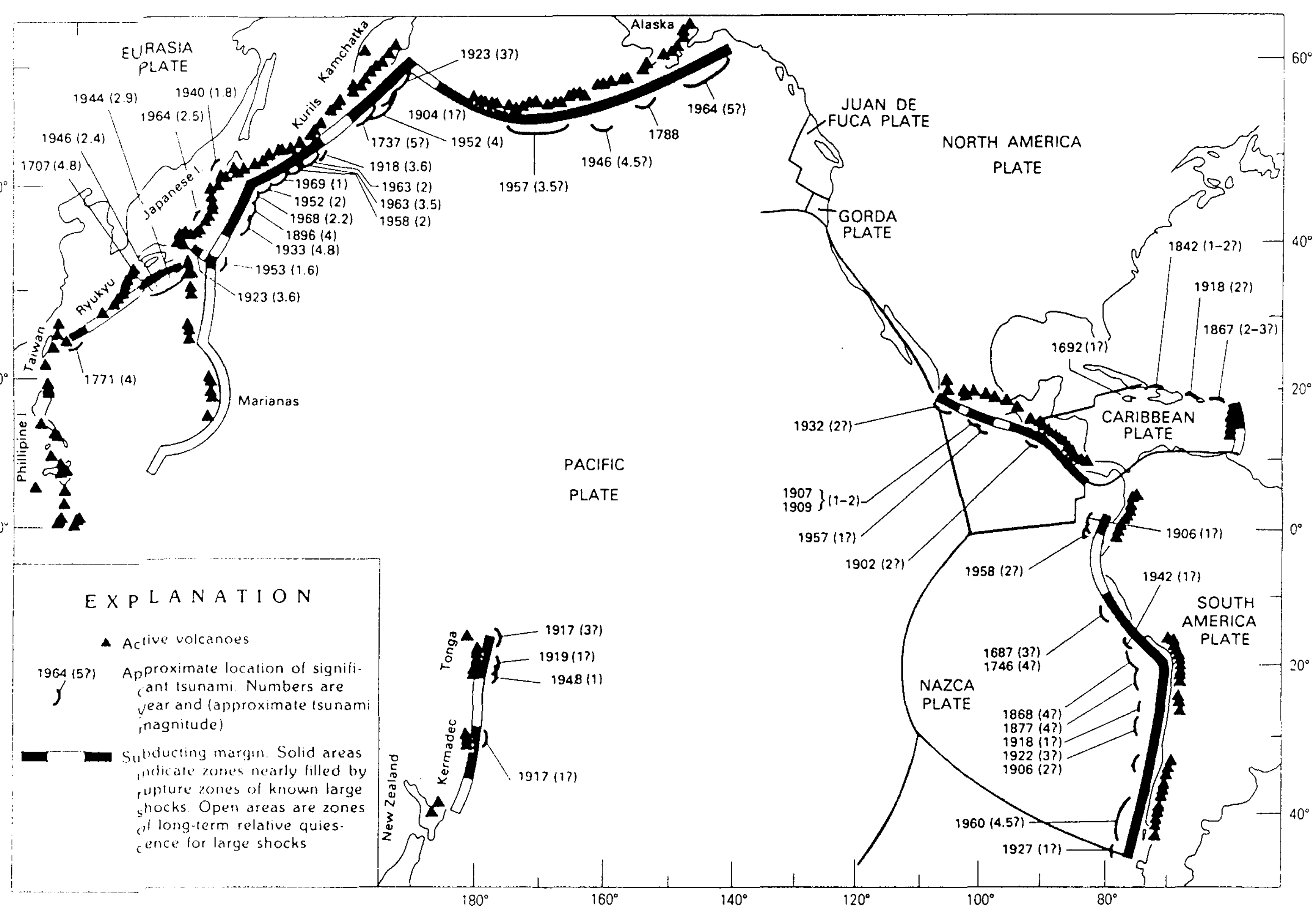
It is generally agreed that the specific prediction of the time, the place, and the magnitude of earthquakes is impossible with present techniques. However, the US National research Council considers that any capability for reliable prediction, "no matter how long the time scale", is more useful than none at all. Thus, the NRC considers it helpful to say that certain densely populated areas in the highly seismic state of California "will almost certainly experience a great earthquake at some time within the next 100–200 years".(NRC, 1976).

The dangers of false earthquake prediction are apparent in, for example, Peru and northern Chile where in 1980 the largest earthquake in the region this century was predicted. The total cost of this false prediction, including lost tourist revenue, was $50 million.

In contrast to the primary hazard of earth–shaking, tsunami forecasting and warning systems are well established. A tsunami warning system was established in 1948 for the Pacific whereby seismograph stations around the Pacific relay information to a Warning Centre near Honolulu, Hawaii. Following the disastrous tsunamigenic Alaska earthquake of 1964,



Some "Major" Earthquake Recurrence Intervals Along Late Quaternary Faults of the Los Angeles Region



Tsunamigenic lithospheric plate boundaries in the Caribbean Sea and the Pacific Ocean (Kelleher, 1979). Tsunami magnitude is $\log_2 H$, where H is the tsunami height in meters.

the Alaska Tsunami Warning Centre was established in 1967 to provide more localised warning and in 1982 this regional responsibility was extended to British Columbia, Washington State, Oregon and California. Similar systems exist in Japan.