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ABSTRACT

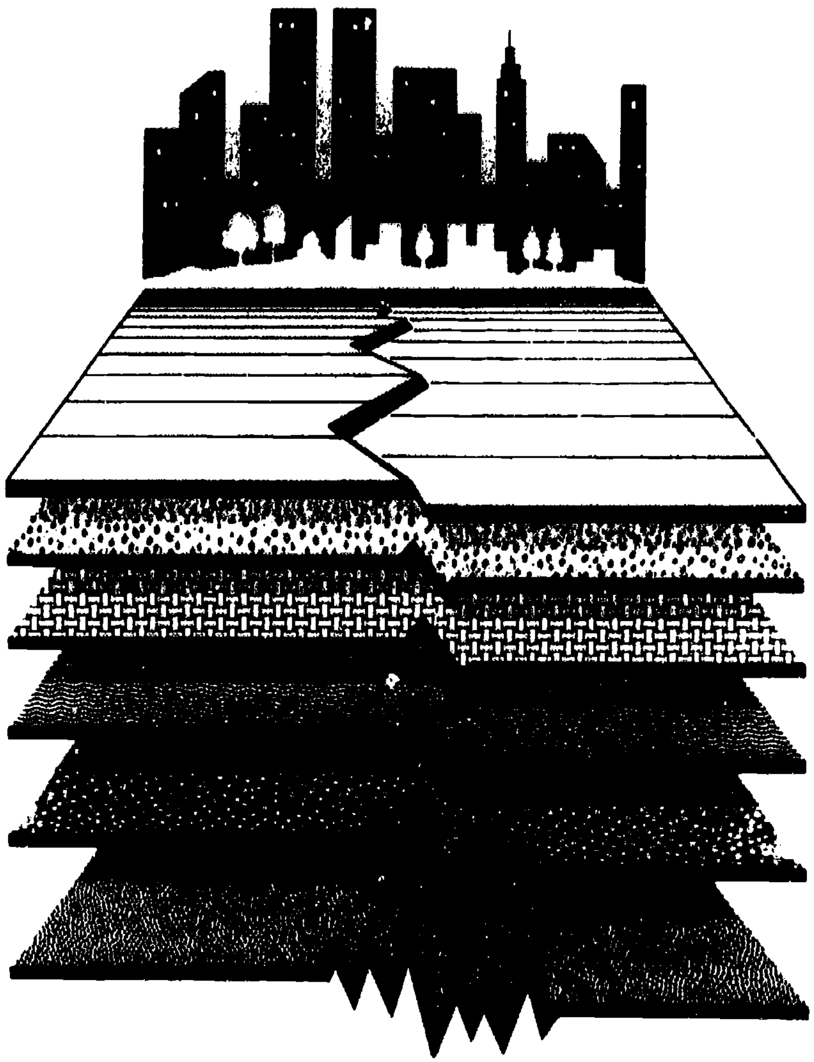
The purpose of this booklet is to provide practical information to owners, operators, and occupants of office and commercial buildings on the vulnerabilities posed by earthquake damage to nonstructural items and the means available to deal with these potential problems. Examples of dangerous nonstructural damages that have occurred in past earthquakes include broken glass, the overturning of tall and heavy shelves, falling overhead light fixtures, ruptured piping containing hazardous substances, and falling pieces of brickwork or precast concrete panels. Typical nonstructural items are described in terms of their earthquake damageability relative to different intensities of shaking. Charts illustrate high-moderate-low statements of life safety and outage risks and percent replacement cost estimates. The most promising countermeasures for protecting each item from earthquake damage are provided. Photographs illustrate actual instances of damage to each type of nonstructural item. Within the document are 23 figures; appended are 12 references and a 14-item annotated bibliography. (MLF)

FEDERAL EMERGENCY MANAGEMENT AGENCY

FEMA 74 / June 1985

Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide

EARTHQUAKE HAZARDS REDUCTION SERIES 1



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Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide

EARTHQUAKE HAZARDS REDUCTION SERIES 1

JUNE 1985

Developed under contract to the
Southern California Earthquake Preparedness Project

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FEDERAL EMERGENCY MANAGEMENT AGENCY

Preface

This project was prepared under contract to the Southern California Earthquake Preparedness Project (SCEPP), a joint State-Federal effort. The State of California participation in SCEPP is coordinated by the California Seismic Safety Commission, while the Federal Emergency Management Agency represents the Federal government. Gilbert Najera was the SCEPP project manager for the development of this booklet, and SCEPP Executive Director Paul Flores, and his predecessor Richard Andrews, also were involved in the determination of the content of this booklet and administration of the contract.

This booklet was prepared by Scientific Service, Inc., a firm specializing in engineering and emergency planning consulting related to natural and manmade hazards. It was written and researched by Robert Reitherman, with the assistance of Dr. T. C. Zsutty, representing architectural and structural engineering expertise in the field of nonstructural earthquake damage respectively. Previous research funded by the National Science Foundation and conducted by Scientific Service, "Computer-Aided Earthquake Analysis For Businesses And Organizations," lead to the development of COUNTERQUAKE, a computer program which includes an item-by-item analysis of nonstructural components, as well as other research products which were utilized in this project. Graphic design was executed by Maureen Ineich, and word processing and editing were accomplished by Michele Boyes, Larue Wilton and Evelyn Kaplan. Chuck Wilton, president of Scientific Service, provided overall management review as well as a detailed critique of drafts of the booklet.

The following companies or governmental organizations and the management staff members who provided liaison services aided the project by providing tours of their facilities so that valid composite models of representative office, retail, and government buildings could be compiled: Barry N. Himel and Eugene F. Huber II, Security Pacific National Bank, Los Angeles; Ed Manes, County of San Bernardino, San Bernardino; Warren Hendry

Von's Grocery Markets, San Bernardino. Nothing in this booklet should be construed to refer to any of these facilities specifically, since it is only the typical, representative building and its nonstructural portions which this booklet treats and discusses.

In addition to the photo credits which will be found with each photograph, the assistance of the following individuals should be acknowledged for generously providing their time as well as access to their photographs for publication here: John F. Meehan, Research Director and Principal Structural Engineer, Office of the State Architect, Sacramento; William T. Holmes, structural engineer, Rutherford and Chekene Engineers, San Francisco; Professor Anshel J. Schiff, Mechanical Engineering Department, Purdue University; Professor Richard Miller, Civil Engineering Department, University of Southern California; Christopher Arnold, President, BSD, Inc., San Mateo.

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1. Introduction

Purpose and Definitions

The purpose of this booklet is to provide practical information to owners, operators, and occupants of office and commercial buildings on the vulnerabilities posed by earthquake damage to nonstructural items and the means available to deal with these potential problems. At the outset, two terms frequently used in the earthquake engineering field should be defined:

Structural - (as in "structural damage," "structural component or member," "structural performance"): The portions of a building that hold it up and resist gravity, earthquakes, wind, and other types of loads are called structural. Structural portions of buildings include columns (posts, pillars); beams (girders, joists); floor or roof sheathing, slabs, or decking; load-bearing walls (or walls designed to hold up the building rather than merely divide up space or keep out the elements as nonstructural walls do); and foundations. Typically, in a building planned by design professionals, the structure is analyzed and designed in detail by a structural engineer. See Fig. 1 for a diagram of structural as distinct from nonstructural parts of a typical building. Note that most of the structure of a typical building is concealed from view by nonstructural materials.

Nonstructural - (as in "nonstructural damage," "nonstructural item," "nonstructural performance"): The nonstructural portions of a building include every part of it and all of its contents with the exception of the structure, or in other words, everything except the columns, floors, beams, etc. Common nonstructural items include ceilings, windows, office equipment, computers, inventory stored on shelves, files, air conditioners, electrical equipment, furnishings, lights, etc. Typically, nonstructural items are not analyzed by engineers, and may be either specified by architects, mechanical engineers (who design heating-ventilating-air conditioning systems and the plumbing for larger buildings), electrical engineers, or interior designers, or are purchased without the involvement of any design professional by owners or tenants after construction of a building.

There are two specific objectives here:

1. Aid the user of this booklet in determining which nonstructural items are most vulnerable to earthquakes and are of most concern.
2. Point the way toward the implementation of cost-effective countermeasures.

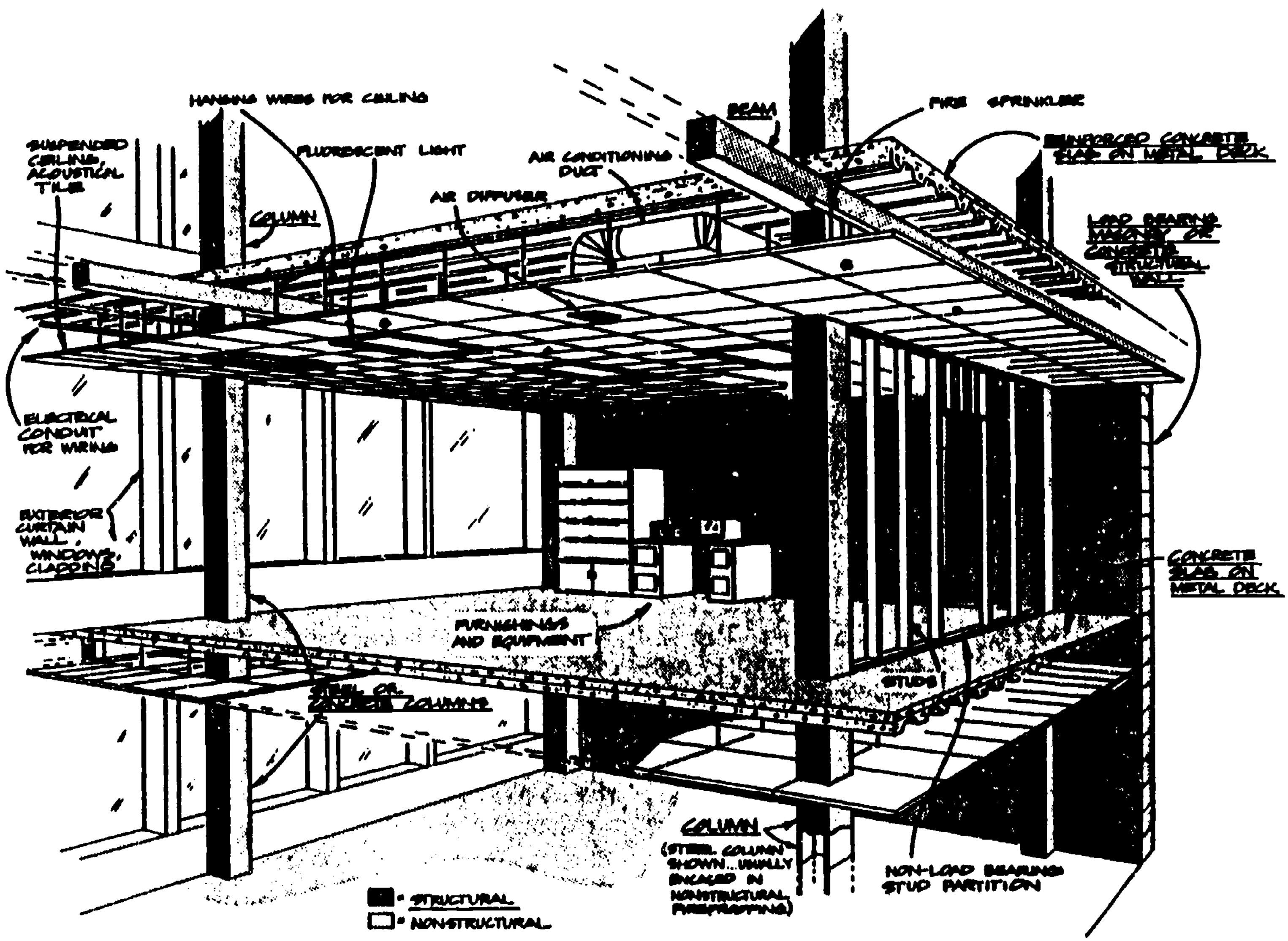


Figure 1

Nonstructural and Structural Portions of a Typical Building

Intended Audience

This booklet has been written with non-engineers in mind: building owners, facilities managers, maintenance personnel, store or office managers, corporate/agency department heads, business proprietors. The intent is to explain in simple terms the sources of the earthquake problems and point the way toward the most promising countermeasures to consider in coping with these problems. (Note that "coping with" rather than "completely eliminating" these problems is our subject: Feasible techniques of reasonable cost for the typical case, rather than impractical or extravagant measures, are our subject matter.)

In some cases, self-diagnosis and self-implementation by the non-engineer may be adequate, and an attempt has been made to provide enough detail to allow for complete implementation of some of the simpler protective measures. There are limits to the self-help approach, however, as explicitly stated below.

The types of buildings covered in this booklet are the most common kinds of office and commercial facilities. Industrial, medical, transportation, or other specialized types of facilities may have their own unique problems and characteristics, though much of relevance to these other types of facilities can be found in this booklet also.

Limitations

If this were a booklet that explained how a person could administer his or her own physical exam, diagnose any health problems, and prescribe and carry out the appropriate treatment, the obvious question would arise: How far along that process can an untrained person proceed before requiring the services of a physician? Wouldn't the layperson get into trouble trying to practice self-help medical care?

In a similar manner, there are limitations and caveats that should be made explicit in this booklet's attempt to instruct laypersons in self-help earthquake engineering. In addition to the individual notes found later which point out specific areas where expertise is required, the general disclaimer should be made here that the use of earthquake engineering expertise is always desirable to improve the reliability of identifying and reducing earthquake risks. It is possible to think of examples where self-help engineering, just like self-help medicine, has done more harm than good. If in doubt about a health problem, consult a doctor, and if in doubt about the "seismic health" of a facility, consult a structural engineer. On the other hand, a number of self-help techniques are commonly recommended by doctors, such as taking one's temperature, treating minor common colds with commonsense measures rather than expensive trips to the doctor, managing one's own diet with only occasional professional advice, and so on. Similarly, this booklet attempts to provide useful advice for self-help earthquake protection measures and presumes the advice will be applied wisely and that expert assistance will be obtained where necessary.

Significance of Nonstructural Damage

Why is nonstructural earthquake damage of concern? Isn't collapse of buildings, which is a structural rather than nonstructural problem as defined above, the only critical potential problem?

Life Safety - The first reason for concern is that people could be and have been hurt by this type of damage. If a 25-pound fluorescent light fixture is not properly fastened to the ceiling, breaks loose during the shaking, and falls on a person's head, it is easy to visualize the resulting injury. Examples of dangerous nonstructural damage which have occurred in past earthquakes include broken glass, the overturning of tall and heavy shelves, falling overhead light fixtures, ruptured piping containing hazardous materials (most commonly natural gas but also more hazardous substances in many industries), falling pieces of decorative brickwork on older buildings or falling pieces of pre-cast concrete panels on newer buildings. See Figure 2.

By and large, the advances in earthquake engineering made in recent decades have been successfully applied to the task of making the structure of buildings in California safer, but there has been comparatively little application of this technical knowledge to the nonstructural portions of buildings. There is a small chance that a building will collapse, but there is a greater chance that nonstructural portions of the building will be damaged. In past large California earthquakes, such as the 1906 San Francisco, 1933 Long Beach, or 1971 San Fernando earthquake, only a fraction of a percent of the buildings collapsed. The odds are in your favor then, although the weakest of our buildings can collapse in moderate or large earthquakes. Collapse, though statistically unlikely, is obviously the most serious consequence to be concerned about, and the major weaknesses which can lead to collapse are largely recognizable ahead of time by structural engineers. Because the structural topic is important but outside the scope of this booklet, it has been only covered in passing in the Appendix.

Property Loss - Recent Federal estimates of earthquake property damage after selected future major earthquakes in California are shown in Figure 3. Note that the immediate property loss attributable to contents, which are only one part of the nonstructure of a building (the air conditioning system, partitions, etc. are not movable contents), is estimated to be a third of the total loss.

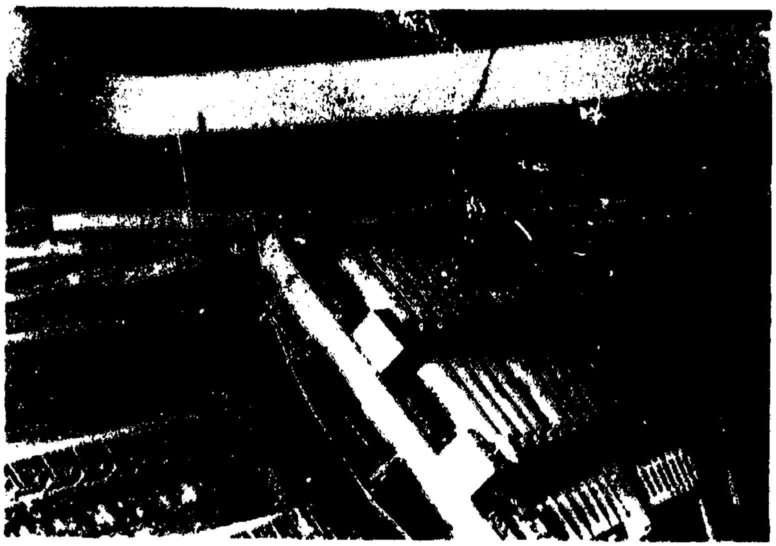
A few individual cases will help illustrate that nonstructural damage can be costly. In the 1971 San Fernando earthquake, a survey of 25 commercial buildings revealed that structural damage accounted for 3% of the total damage, electrical and mechanical for 7%, exterior finishes 34%, and interior finishes 56%. A survey of 50 high rise buildings, which were far enough away from the earthquake fault to experience only mild shaking, showed that none had major structural damage, 43 suffered damage to drywall or plaster partitions, 18 suffered damaged elevators, 15 had broken windows, and 8 incurred damage to air conditioning systems, (Ref. 1). In the case of one seven story Holiday Inn in this 1971 earthquake, damage representing over 10% of the construction cost was experienced. Of this $363,000 in damage in 1983-value dollars, only $5,000 was structural damage, while $358,000 was nonstructural, (Ref. 2). The original 1971 dollar figures of $2000 in structural damage and $143,000 in nonstructural damage have been multiplied by 2.5 to account for inflation from 1971 to 1983.

Reporting on the damage in a large multistory office building damaged in the 1972 Managua earthquake in Nicaragua, two earthquake engineers noted that "the structural performance of the building was good . . . in terms of non-structural damage, the building was a mess . . . in the end, although the building remained structurally sound the non-structural components were a shambles and the rehabilitation is very slow and very expensive." (Ref. 3.)

Interruption of Essential Functions - In addition to the life safety and property loss considerations, there is the additional possibility that nonstructural damage will make it difficult or impossible to carry out the functions normally accomplished in a facility. After the serious

a. VA Hospital, 1971 San Fernando earthquake

b. Banco Centrale, 1972 Nicaragua earthquake



c. Olive View Hospital telephone equipment, 1971 San Fernando earthquake

d. Banco Centrale, 1972 Nicaragua earthquake

credits: a, b, c, d: John F. Meehan

Figure 2

Examples of Hazardous Nonstructural Earthquake Damage

Fault	Loss to Buildings ($ in Billions)	Loss of Contents ($ in Billions)	Total Loss ($ in Billions)
Northern San Andreas	25	13	38
Hayward	29	15	44
Newport-Inglewood	45	24	69
Southern San Andreas	11	6	17

Estimates uncertain by a possible factor of two to three.

Source: Federal Emergency Management Agency, "An Assessment Of The Consequences And Preparations For A Catastrophic California Earthquake: Findings And Actions Taken," January 1981.

Figure 3

Estimates of Property Losses For Representative Earthquakes

life safety threats have been dealt with, post-earthquake downtime or reduced productivity is often the most serious risk.

In one 27-story high rise in Los Angeles subjected to only a light or light-to-moderate intensity of shaking in the 1971 San Fernando earthquake, the tenant companies in the building suffered about $37,000 in 1983-value dollars in lost employee labor losses, primarily because the elevators were out of service. (Operation of the elevators immediately after the earthquake, before they had been checked, caused tangled cables to foul, and damage occurred which could have been avoided.) The building owner's property damage losses, primarily due to elevator repairs and partition patching and painting, amounted to $108,000. In a nearby 19-story office building where the elevators were not damaged, occupants incurred about $14,000 in expenses to clean-up interior damage and disarray, largely attributable to re-filing. These costs corresponded to a light amount of nonstructural damage. The earthquake recording instruments in these two buildings recorded maximum accelerations or shaking intensities only about one fifth as strong as have been recorded in other buildings in earthquakes and the damage could have been much worse (Ref. 4). In some cases, clean-up costs or the value of lost employee labor are not the key measures of the post-earthquake impact of the earthquake. For example, for a financial business which must remain operational on an hour-by-hour or minute-by-minute basis to maintain essential services and remain in communication with transactions occurring elsewhere, damage to communications or computer equipment, or spilled files, represent less tangible but more significant outage costs.

Causes of Nonstructural Damage - How does an earthquake cause nonstructural damage? One of the easiest mechanisms to visualize, but the one which accounts for the least amount of damage, is the category of direct geologic impacts, such as the rupture of the earth along a fault line, a landslide caused by the shaking, tsunamis (seismic sea waves), or liquefaction (the temporary "mushy" condition of certain types of normally firm ground when the soil shakes). These effects are usually localized though they may be severe; they are beyond the scope of this booklet.

Moving on to our subject of the effects of the shaking of the ground on buildings and more particularly their nonstructural portions, two different damage processes can be identified: inertial or shaking effects on the nonstructural objects themselves, and the imposed distortion of their shape which is caused by the swaying of the surrounding structure on built-in items.

Inertia - When the building is shaken, the base is moved violently by the moving earth during the earthquake, and every portion above experiences inertia forces, similar to whiplash effects in rapidly accelerating or decelerating automobiles. Although the engineering aspects of earthquake inertial forces are slightly more complex than a single principle of physics, the law first formulated by Sir Isaac Newton, $F = ma$, or the force is equal to the mass times the acceleration, is the basic principle involved. In general, greater forces result if the mass is greater (if the building or object within the building weighs more) or if the acceleration or severity of the shaking is greater.

A file cabinet, emergency power generator, freestanding bookshelf, office equipment, or items stored on shelves or racks can be damaged because of inertia: They are shaken, and if there is only friction to restrain them, a severe earthquake can be capable of causing them to overturn, impact against other objects, or fall to the floor. The heavier the file cabinet, emergency power generator, etc., the greater the earthquake forces.

To design bolted connections, restraining chains or wires, or other protective devices, engineers use a percentage of the weight of the object as the horizontal earthquake force which must be resisted by their designs. There are also vertical earthquake forces to consider. The Uniform Building Code (UBC) is the model code used in the western United States, and its seismic regulations, which are largely developed and periodically revised as a service of the Structural Engineers Association of California, are influential as a model in many other countries as well. Some major cities in California, such as Los Angeles or San Francisco, publish their own building codes, although these codes usually closely resemble the Uniform Building Code.

The UBC, in its Table 23-J, lists the horizontal seismic force factors which should be used in the design of partitions, parapets, chimneys, ornaments, tank supports, storage racks over 8 feet tall, equipment or machinery, and suspended ceilings. Depending upon the type of building (the design forces are greater for fire stations than for ordinary office buildings, for example), the geographic location, and other factors, the usual specified horizontal force is 30% of the weight of the object. If the loaded storage rack weighs 1000 pounds, the engineer must design its bracing and its attachment to the floor and/or wall to handle horizontal forces in any direction of 300 pounds, for example.

Surveys of actual buildings indicate that many nonstructural items are never designed for any horizontal forces but are instead installed according to common construction practice that varies little from seismic to non-seismic areas. The above listing of nonstructural items or components is also rather general, except for an occasional specifically described item such as "storage racks with upper storage level at more than 8 feet in height." Many nonstructural items (such as the more common office or retail situation of storage shelves up to about 7 feet six inches in height) are not covered at all by the letter of the law. The fact that the building code is not as specific about these nonstructural items as it is about the structural portions of buildings is indicative of the general intent of the earthquake regulations to provide a minimum level of life safety and to avoid legislating property damage-control measures. In general, "life safety" and "prevention of structural collapse" have been used almost interchangeably in the thinking underlying the earthquake regulations in the building code, although it is becoming apparent that there are significant nonstructural dangers to life and limb as well, and in some cases, potential nonstructural property losses or outages are strong reasons for obtaining more than the code minimum level of protection.

The point of this discussion of the building code is that the problem of nonstructural earthquake damage is not automatically solved for you, the owner or occupant of a building, by mere conformance of construction with the building code.

Distortion of the Enclosing Building - The other major way, besides inertia or shaking, in which a nonstructural item may be damaged, is the imposed deformation problem: When the building structure is shaken, it must distort or bend out of shape; the top of a mid-rise building may lean over a few inches and in the case of a tall office tower this may actually amount to a few feet. Windows, partitions and other items that are tightly locked into the structure are forced to go along for the ride, and as the columns or walls lean over a certain amount and become slightly out-of-square if only for an instant, the window or partition must also lean over the same amount if it is tightly confined. The more space around a pane of glass where it is mounted between stops or moulding strips, the more distortion the pane can accommodate before the glass itself is forced to distort. Brittle materials like glass or plaster or drywall partitions cannot tolerate any significant distortion, so once the gaps around their edges are taken up by the motion, they will quickly crack. Most partitions are damaged not because they themselves are shaken and are damaged by inertia as discussed above, but rather because the building around them distorts.

Shaking Intensity and Nonstructural Damage - Earthquake shaking is difficult to precisely define. The ground shakes to a certain extent or with a certain amplitude, but the shaking also must be described in terms of its frequency. Low frequency vibrations are slow rocking motions while high frequency motions are more of a chattering, rapidly vibrating type of motion. Earthquakes typically contain a complex mixture of frequencies of motion. The descriptive scale shown in Figure 4 takes only the overall extent of motion into account and not its frequency content, and hence, it is only a simplified and largely non-quantified description of ground shaking. However, it will be adequate for our purpose of approximately estimating nonstructural damage. This intensity scale, like others in use in other countries, is properly shown with Roman numerals, which indicate the lack of precision.

The scale in Figure 4 is essentially the Modified Mercalli intensity scale, which was originally devised by the Italian seismologist Giuseppe Mercalli in 1902, modified (hence the "Modified" in its name) by two famous American seismologists, Harry Wood and Frank Neumann, in 1931, and further revised by another famous seismologist, Charles Richter in 1956. In the version shown here, we have taken the liberty of further revising the scale to emphasize nonstructural effects common to the present day California context. In so doing it borrows extensively from work by Dr. Robert Nason of the U.S. Geological Survey, who has studied the correlation of the toppling of items from shelves and other nonstructural effects with the intensity of ground shaking as measured by instruments and as observed from other effects.

Although the Modified Mercalli is a 12-point scale, levels XI and XII are not used here since they describe soils failures ("rails bent greatly," "underground pipelines completely out of service") which can occur at various intensities of shaking. The other traditional descriptions for XI and XII, such as "damage nearly total", are not referenced to construction characteristics (damage to what is nearly total?) and do not appear relevant in the California context. "Damage nearly total" is not an accurate description of shaking-caused damage for any given neighborhood that underwent the 1906 San Francisco, 1964 Alaska, 1971 San Fernando, or other U.S. earthquakes, and hence it is difficult to apply. In these earthquakes, only a minority of buildings in any given area collapsed, and on the scale of a city, those buildings receiving extreme or total damage were in a very small minority. These explanations are added to indicate why the scale as shown here differs from that found in standard textbooks.

The individual numbered intensity levels are bracketed here into 3 large categories: light, moderate, and severe. These 3 levels of intensity are used in describing the vulnerability of individual nonstructural items to shaking in Chapter 3. Greater precision is generally not particularly useful nor scientifically valid unless a detailed study of a given building and its nonstructural items is conducted.

Keep in mind that the intensity scale, or predictions of how the ground will shake in future earthquakes at particular locations, are attempts to rank the intensity of

LIGHT

I
II
III   I-IV: from barely perceptible to mild shaking
IV   without damage

V: Felt by nearly everyone, and many are awakened if the earthquake occurs at night. Some dishes or other fragile shelf items fall and break. Cracked plaster or drywall in a few places. Movement of trees, power lines, and other tall flexible objects noticed. Pendulum clocks may stop. Water may slosh in swimming pools. Only a few shelf items in grocery stores shifted or fallen. Flexible items such as liquids in containers, tall floor lamps or chandeliers, etc., may move more than other more rigid objects such as furniture. Windows or contents of cabinets may rattle.

VI: Felt by all, many frightened. The top portion of some unreinforced brick chimneys on houses are damaged. Some furniture shifted slightly. Shelf items throughout a grocery store may fall, but not to the extent that it is difficult to walk through all of the aisles. Cracks or occasional falling of pieces of plaster. Occasional large storefront windows cracked.

MODERATE

VII: Everyone notices and is alarmed by the earthquake. Persons driving automobiles notice the shaking. Unreinforced chimney damage common to older houses but affects less than half of buildings. Many or most aisles of grocery stores blocked by fallen shelf items. Some spring mounted but not seismically restrained heating-ventilating-air conditioning equipment begins to shift but generally does not fall off its spring supports.

VIII: Many find it difficult to keep balance while standing. Shaking interferes with driving of automobiles. Widespread unreinforced chimney damage. Pipes may leak in buildings. Suspended ceilings without diagonal bracing partially fall. Spring mounted mechanical equipment without seismic restrainers breaks supports and falls. Tall unanchored shelving and storage racks lose contents or tip over.

SEVERE

IX: The shaking is very alarming to everyone and it is very difficult to stand. Widespread overturning of unanchored equipment if about twice as tall as wide, including some television set-sized items on tables or desks. Most unanchored shelving overturns. Sliding of other unanchored items.

X: Unusually severe ground motion, such as has been observed in only a very few earthquakes. People thrown to the ground and cannot stand up. Most unanchored nonstructural objects except tables and desks fall. Objects do not fly through air but may bounce and overturn due to vertical shaking.

Figure 4
Modified Mercalli Intensity Scale
(modified further to emphasize California nonstructural damage indicators)

shaking of the ground -- the shaking in upper levels of buildings is usually amplified and more severe, and thus on the tenth floor of a building the local effects might be describable as VIII on the scale, whereas on the ground floor it might appear to be only VI or VII. For tall office buildings, more on this topic is included in Chapter 3.

More frequently reported in the press is the magnitude of an earthquake, partly because magnitude can be deciphered and calculated from a seismographic record within minutes and reported to the media, while intensities are only slowly plotted on maps after reports are received over a period of weeks.

Magnitude is a quantitative indication of the overall size of the earthquake. A large magnitude earthquake, a 7 or an 8, may cause high intensities nearby but only small intensities further away, for example, which is quite logical if it remembered that the magnitude number is a single number describing the overall size of the earthquake, while obviously the shaking intensity cannot be the same everywhere. Even a magnitude 5 or 6 earthquake can cause significant nonstructural damage and major structural damage if it occurs nearby: The 1933 Long Beach and 1971 San Fernando earthquakes were both only about magnitude 6 1/2 earthquakes, for example, but they caused some severe damage over the areas of the Los Angeles metropolitan region where they were centered.

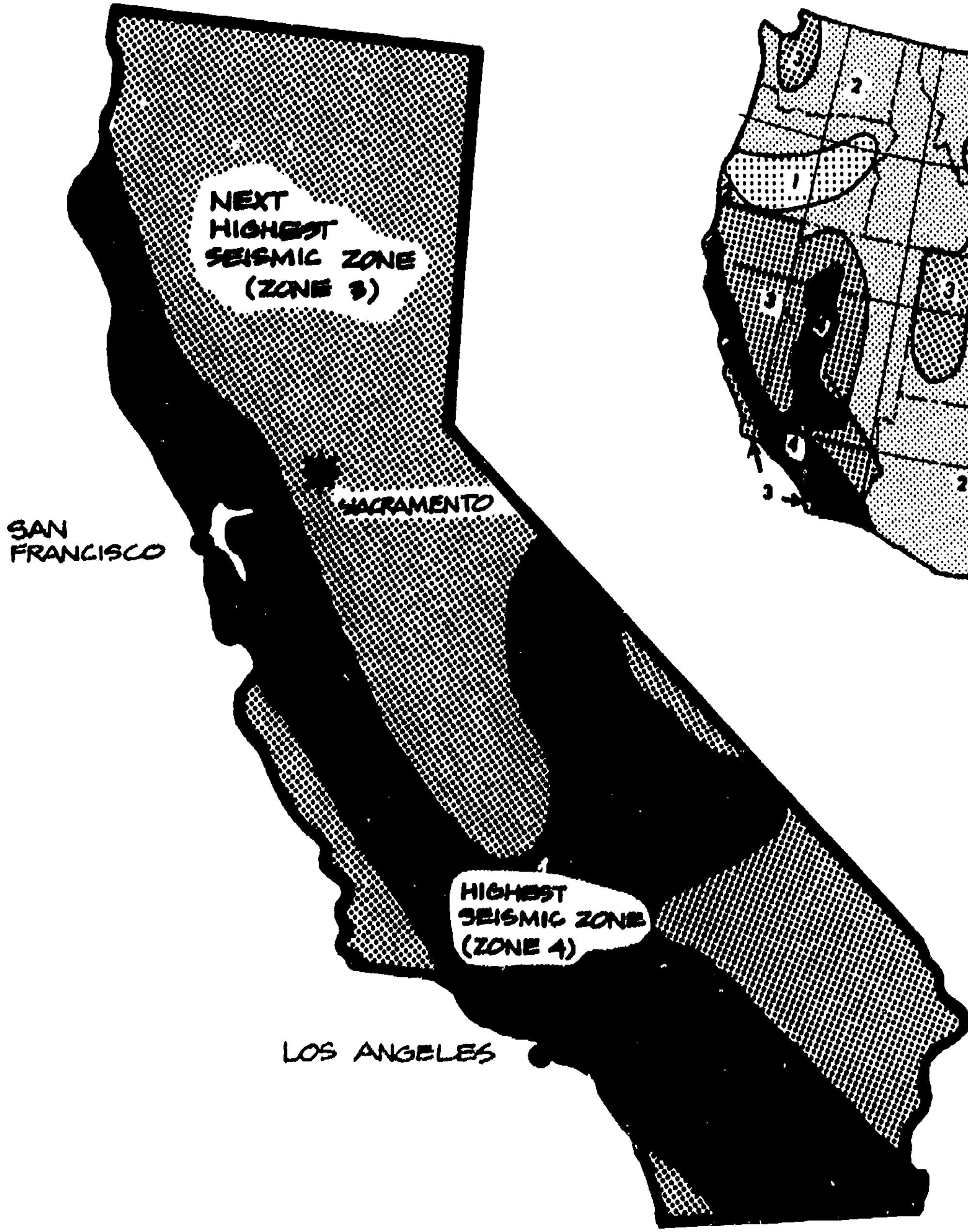
Charles Richter, who with his colleague Beno Gutenberg devised the first magnitude scale in 1935, has explained that "Magnitude can be compared to the power output in kilowatts of a broadcasting station. Local intensity on the Mercalli scale is then comparable to the signal strength on a receiver at a given locality, in effect, the quality of the signal. Intensity like signal strength will generally fall off with distance from the source, although it also depends on the local conditions and the pathway from the source to the point", (Ref. 5).

Geographic Location And Seismic Risk

Approximately 80% of California's population, and perhaps an even higher percentage of its industrial, commercial, and governmental buildings, are located within the Uniform Building Code's highest seismic zone out of the five zones in the United States. The remainder of the state is located in the next highest zone. See Figure 5.

These Uniform Building Code seismic zones are used by engineers in the earthquake design of most ordinary buildings and any nonstructural components which might receive their attention. The zones take into account the fact that in California there are numerous active earthquake faults which could generate damaging earthquakes, that some faults rupture and cause earthquakes more frequently than others, and that some faults are capable of causing larger earthquakes than others. If only the well-known San Andreas Fault were considered, much less territory would be included in the highest seismic zone. Other maps have been prepared by researchers which attempt to predict how the ground will shake from a single given earthquake, such as on the northern or southern segments of the San Andreas, but a more general map such as in Figure 5 is a better basis for evaluating all of the potential earthquakes which could affect a given site. For some important facilities, such as hospitals or major tall buildings, more detailed estimates of how the ground will shake at a given location are produced by seismologists and engineers. For our purposes, the map of Figure 5 is adequately detailed.

The engineer uses this map in carrying out computations of seismic forces, but the non-engineer can



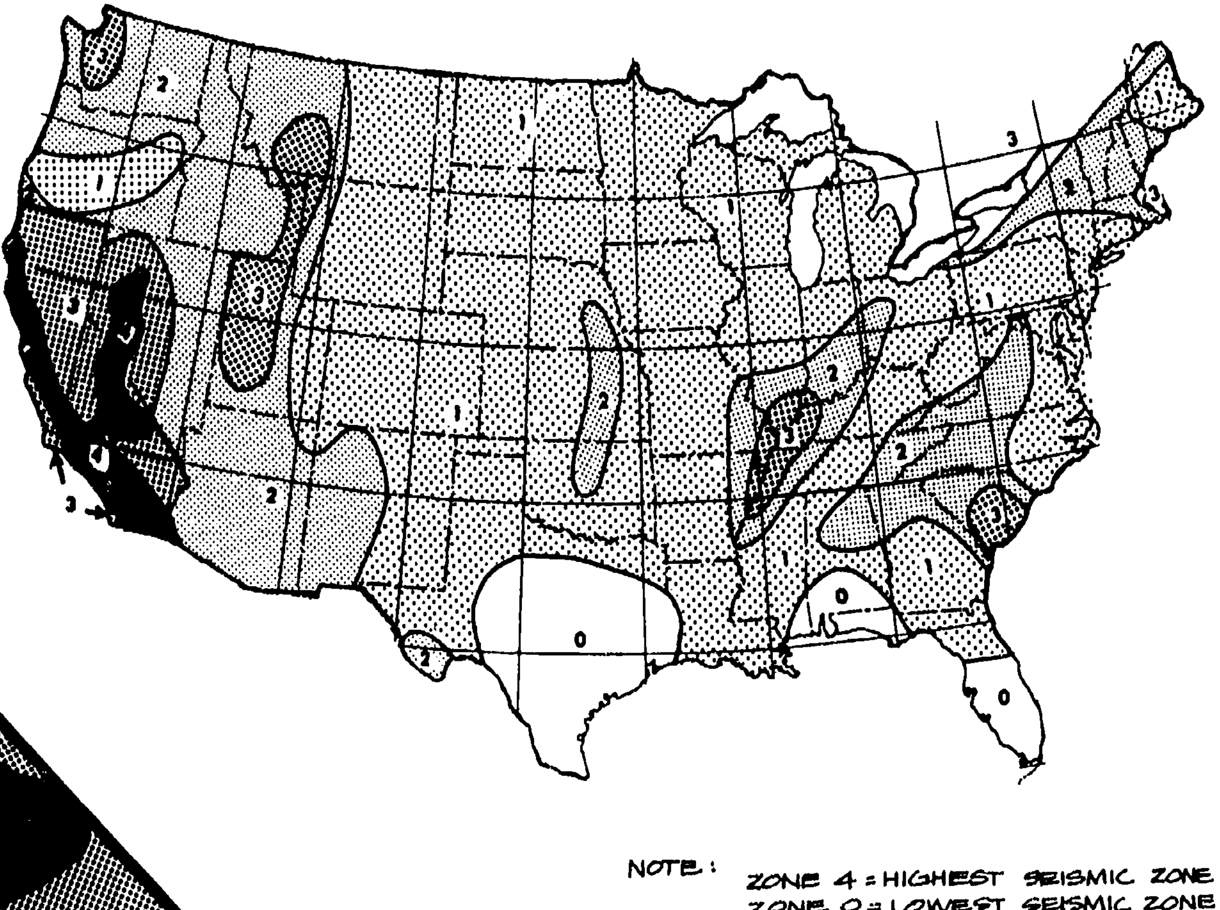


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Figure 5

Uniform Building Code Seismic Zones

obtain an approximate idea of the risk of experiencing ground motion of different intensities from this map as well. The word "approximate" is used partly because the task of estimating how often a fault will cause an earthquake of a certain magnitude, and how this energy will be transmitted to and shake a particular site, is complicated by many uncertainties. In Figure 6, an attempt has been made to associate the chance of experiencing different intensities of shaking with the two different seismic zones for California. The light, moderate, and severe intensities correspond to Figure 4. Note that in zone 4, there is virtually a 100% chance of experiencing light shaking or worse during 25 years; in zone 3, there is about a 60% chance of experiencing at least light shaking.

For companies with elaborate risk management programs, these probabilities may be useful, in combination with the estimated effects of shaking on individual nonstructural components as presented in Chapter 3, in cost-benefit analyses. For most purposes, however, the following guidance is probably adequate: If located in zone 4, the highest or worst seismic zone, plan for a severe intensity and look carefully at the information in the next chapter in this light. If located in zone 3, the moderate level of intensity is a reasonable basis for planning. Adjust this general guidance if a facility is more or less important than average: Just as the building code imposes more severe requirements on the fire station than the ordinary building, so it would make sense to plan for a severe intensity of shaking in zone 3, rather than just moderate, if an especially valuable or essential piece of computer equipment, valuable artwork, or especially hazardous materials were involved. In any event, the minimum requirements of the Uniform Building Code or its local variant, which is legally binding rather than merely voluntary, should be followed even if merely minor nonstructural remodelling work is being done which does not require a building permit.

Earthquake Prediction

In the event that practical methods for predicting the time, place, and size of earthquakes are developed in the future, what would be the effect on the validity of the guidance offered in this booklet? In general, there would be no change required in the advice, but the priorities assigned to nonstructural as well as structural upgrading projects would drastically increase, and the amount of time to implement these projects might be very limited. Expedient and temporary measures, such as placing the contents of shelving on the floor, or taping windows to prevent the fall of fragments, or moving contents to another location, might be feasible in the context of a short term prediction. If the prediction is somewhat vague as to time, such as a prediction of an earthquake "sometime next month", and if evacuation would not be feasible in light of its costs and the costs of shutdowns, continued use of buildings and their nonstructural portions will probably be the rule.

Nonstructural countermeasures such as those outlined here will probably appear the most promising in the context of an earthquake prediction. In the case of structures, temporary shoring of bracing may be feasible, such as installing guy cables (like the cables which brace tall antennas), erecting plywood sidewalk canopies as used on urban construction projects to protect passersby from falling objects, or adding timber or steel shoring posts and bracing diagonals in between floor levels.

After a prediction, a "run on the market" may well occur as far as structural engineers, contractors, and specialized construction materials are concerned, and time will be very limited. The best advice is to act now in an orderly and convenient way on the basis of the general prediction that most of California's urbanized areas will be at least significantly shaken every generation or so rather than to wait until a specific short-term prediction may occur.

	INTENSITY (see Figure 4 for definition)		
ZONE (see Figure 5 for location)	LIGHT	MODERATE	SEVERE
UBC ZONE 4	60%	35%	5%
UBC ZONE 3	40%	20%	1%

Figure 6

Approximate Chance of Experiencing Intensity During 25 Year Period

2. Typical Conditions Found In Office, Retail, and Government Buildings

High Rise Office Buildings

In addition to the characteristics of the specific nonstructural systems found in any given office building, there are four seismic factors which apply to tall high rise office towers: (1) Taller buildings can amplify the motion of the ground, and in their upper portions the shaking can be more intense than at the ground or in a stiffer, shorter building; (2) They are more sensitive to distant earthquakes; (3) Tall buildings can contain several thousand occupants rather than only a few dozen or hundred; (4) Most of the building will be unusable without elevator service. It is really the stiffness of the building, which is dependent upon its precise materials, presence of structural walls in addition to frames, configuration, and other factors, rather than just its overall height, which is pertinent, but here we will generalize to assume that all tall buildings are flexible.

(1) The top floors of a high rise building (say 8-10 stories or taller) will experience stronger shaking than the lower floors or ground level. For example, according to one recent seismic design guideline (Ref. 6), the top floor of a building can be assumed to shake twice as vigorously as the base for purposes of designing nonstructural anchorages, with intermediate stories shaking proportionately: Three-fourths of the way up the height of the building, such as at the 15th floor of a 20 story building, the shaking would be one and three fourths as great as at the ground level, according to this approximate rule.

(2) Tall buildings have a natural tendency to respond to vibrations with a slow-paced back and forth swaying: The tall building is like the palm tree which swings back and forth every few seconds while the nearby short and stiff shrub flutters rapidly in the same breeze. The ground motion at a site which is distant from an earthquake is generally of this slow-paced, lower frequency variety while the more rapid-paced vibrations occur nearer the fault which released the earthquake. In the 1952 Kern County earthquakes, it was generally only

the tall buildings in downtown Los Angeles which responded significantly to the slow rocking motion generated by the earthquakes which were 100 miles away, (Ref. 7). This heightened sensitivity to distant earthquakes means that tall office towers will in effect "feel" more earthquakes than shorter buildings that do not tune in to this rolling motion. For nearby earthquakes, all buildings will be affected to some significant degree. Hence, tall buildings are at greater risk as far as their nonstructural portions are concerned. The structural system holding up a tall building in California is generally subjected to very thorough engineering to ensure its adequacy in earthquakes, but most nonstructural items were not included as part of the engineer's responsibility in the design of the building.

(3) The large number of occupants in the tall building also differentiates it from other buildings from a seismic point of view. Nonstructural damage, for example, disruption of water and electrical service to areas such as rest rooms, food service facilities, and air conditioning mechanical rooms, are easier to cope with if a smaller number of people are involved. In a tall building, if people must temporarily stay in the building because of internal outages (lack of elevator service) and external outages (cordoned off areas, blocked or jammed streets and freeways, lack of public transit), the problems will be severe.

(4) The last factor which sets the tall building apart is its extreme dependence on elevators. Only the lowest few floors, or a small percentage of the total space, would be usuable without elevator service.

Typical Nonstructural Items - The nonstructural components listed in Figure 7 are the items most commonly found in a typical high rise office building. Priority ratings are suggested, though these can only be offered as an approximate guide since the functions considered essential, or the items of most property value, can vary from one building to the next, as can the precise construction characteristics. Real buildings are rarely typical in regard to every aspect of their construction and especially with regard to the details of their use. Photos of representative nonstructural items are shown in Figure 8.

Typical Building Layout - Figure 9 illustrates a representative layout for a high rise office building. There are several nonstructural characteristics to note. Elevators are usually grouped together, and often centrally. While retroactive regulations in effect in California since 1975 have imposed more stringent earthquake-resistant construction standards on elevators, the elevators will still probably not be operable immediately after an earthquake. Seismic switches are designed to be triggered by the earthquake and they will cause the cars to move to the nearest floor, open the doors, and then shut them off. An example in Chapter 1 was given of severe damage suffered by an elevator system because it was operated with misaligned cables after an earthquake before being checked. In the 1971 San Fernando earthquake, almost 500 elevators were damaged in such as way as to pose a threat to cab occupants though few people were using them at 6 a.m. when the earthquake occurred. For these reasons, signs should be posted that inform occupants not to use the elevators in case of fire or earthquake. See Figure 10.

The stairways, due to fire regulations, are separated rather than grouped, and there will be a minimum of two. Even if there is damage to all elevators and one stairway, there will be at least one other means of exiting the building. In many multi-story buildings, the stairwell doors are locked from the inside for security reasons except for the bottom level where people are supposed to

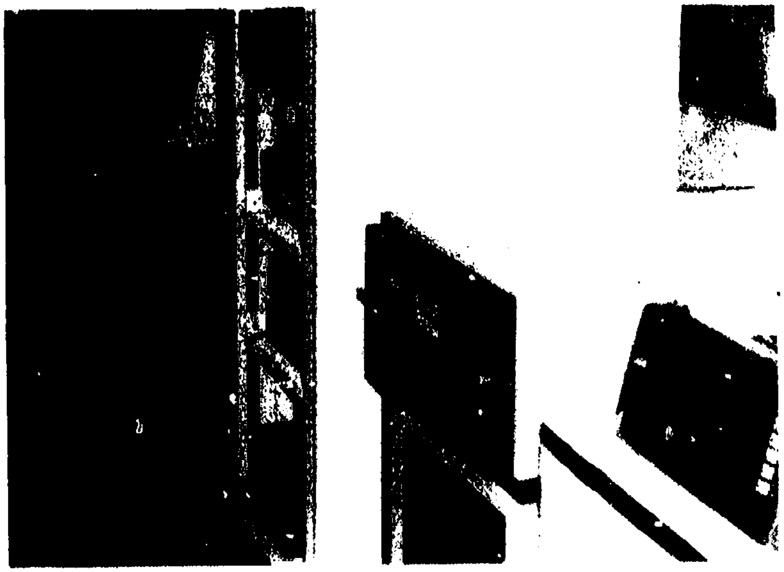
High Priority For Seismic Evaluation

- o Computers
- o Heavy ceiling-located objects: light fixtures, ducts, diffusers, and pipes
- o Exterior signs
- o Exterior pre-cast concrete cladding
- o Emergency power generator
- o Elevators
- o Valuable and fragile artwork (sculpture)
- o Water heaters; any natural gas piping
- o Mechanical room equipment
- o Tall file cabinets
- o Tall storage racks or shelving
- o Battery-powered emergency lights
- o Fire extinguishers and cabinets, fire sprinklers
- 0 Large electrical equipment, transformers

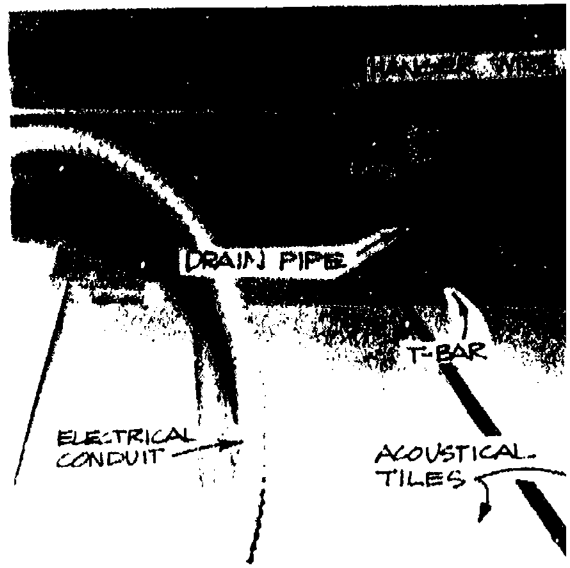
Lesser Priority For Seismic Evaluation

- o Miscellaneous furnishings less than 4 or 5 feet off the floor
- o Furniture
- o Desk top office equipment
- o Partitions
- o File cabinets, short or 2-drawer
- o Lightweight ceilings

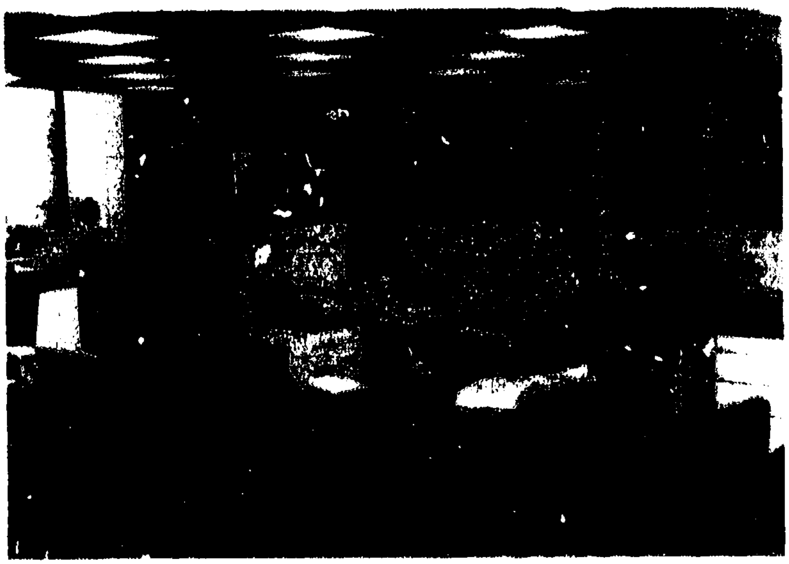
Figure 7
Typical High Rise Office Building
Nonstructural Items



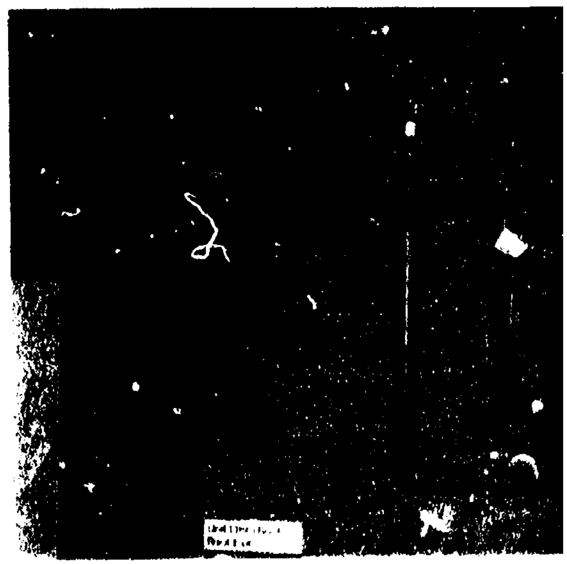
a. Computer on raised floor



b. Service space above suspended



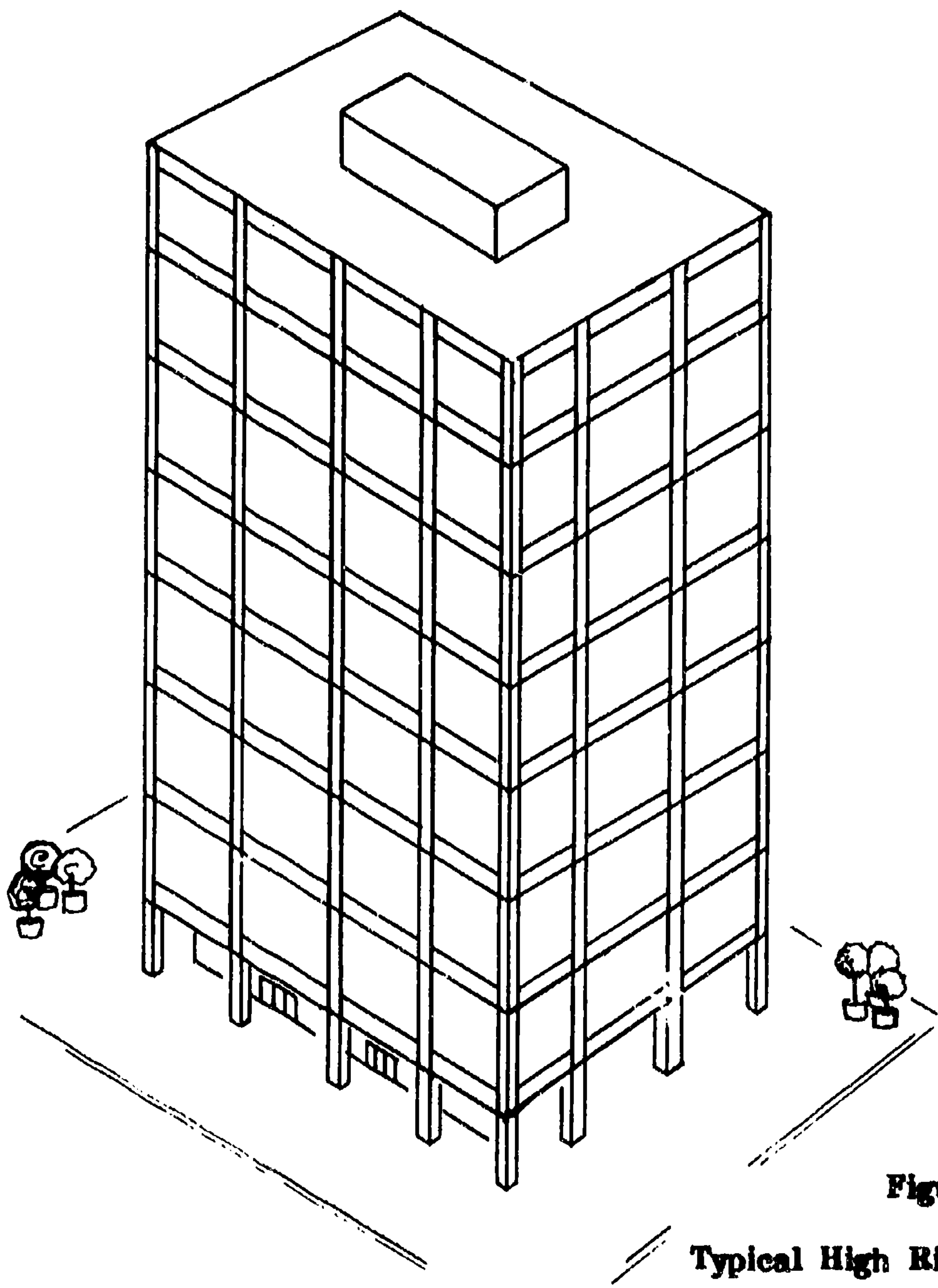
c. Open plan office area



d. Fire sprinkler control valves

Figure 8

Typical Scenes of Nonstructural Items in an Office Building



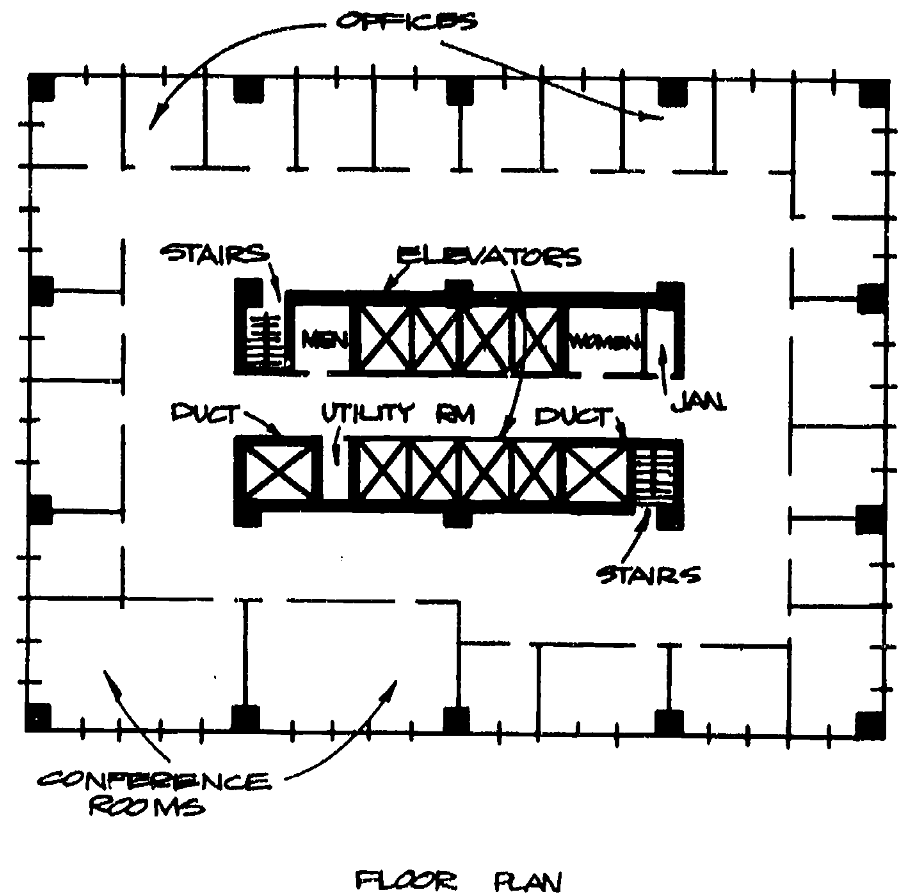


Figure 9

Typical High Rise Office Layout

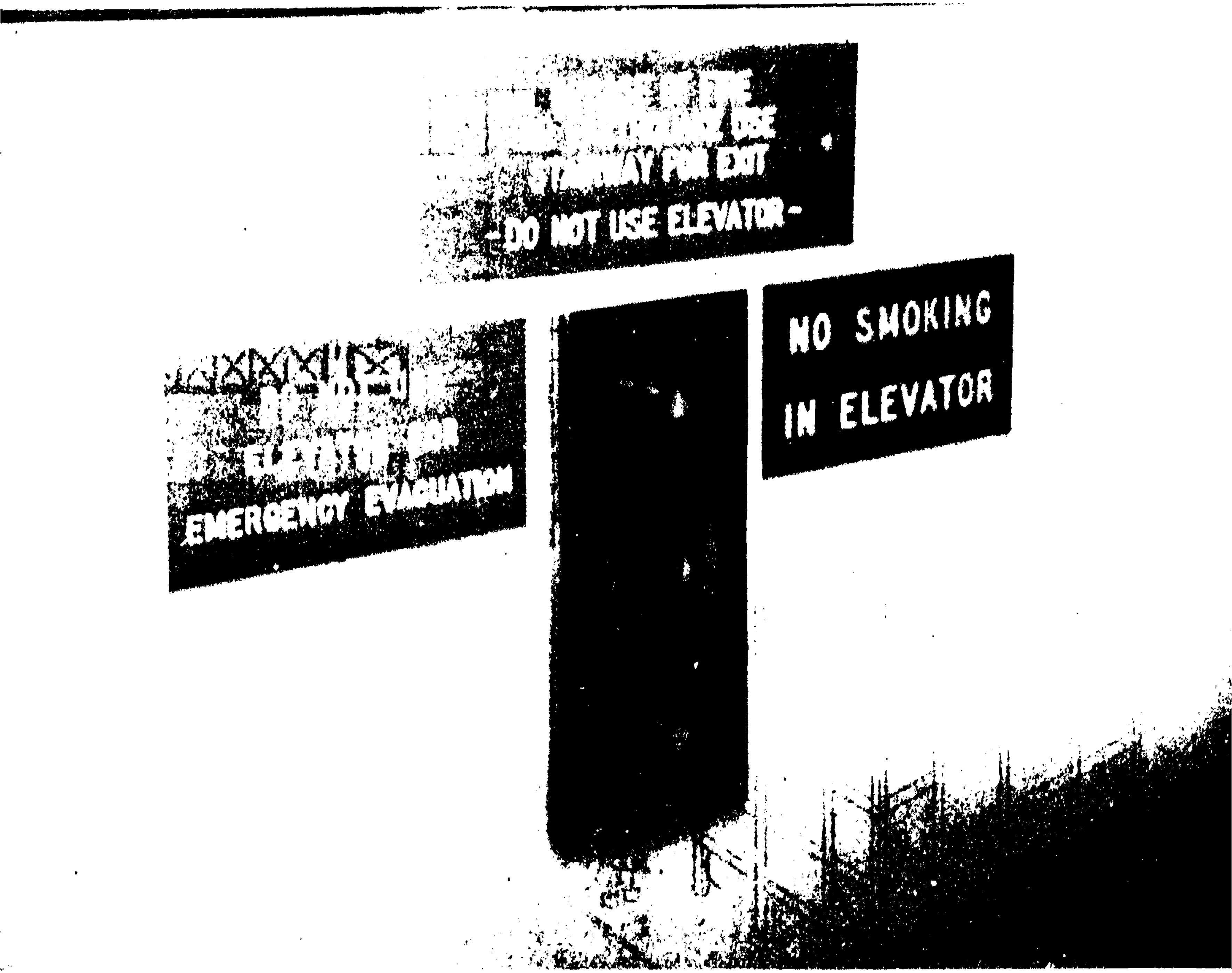


Figure 10

Appropriate Earthquake Sign by Elevator

exit. In the case of damage to a stairway at one level of a building, if the doors at this level are quickly unlocked, it will allow for a cross-over to another stairway. The exterior walls are often largely composed of glass, and this is a potential falling object hazard inside and especially outside the building: Re-grouping areas for occupants after they have evacuated the building should not be located within about 50 feet of overhead windows.

The structural system's story-by-story layering of the building is often matched in an organizational sense, for emergency purposes. Often there is a floor warden or floor manager for each floor in charge of directing emergency procedures in the case of bomb threats or fires, and this same system can be adapted for use in earthquakes. Planning for fires is especially relevant since in this case also, the elevators are to be avoided.

Mechanical rooms where the heating-ventilating-air conditioning equipment is located are often found at top, mid-height, and bottom of tall buildings. Some water tanks are located at the top because this provides constant water pressure down to each upper floor without having to constantly pump water at high pressure up to each floor. Air conditioning equipment cannot be located all at one level, such as the basement, because the distance to upper floors and thus the length and size of air ducts required, would be excessive. This means that after an earthquake, there will be several potential places for mechanical equipment damage that should be quickly checked.

Retail Store

Unlike the tall office building, the retail store, such as the supermarket, will typically be located in a one story building or on the ground floor of a low-rise building, or occasionally, as in a large department store, comprise a two or three story building. This simplifies or reduces many of the nonstructural problems.

From an operational and emergency planning standpoint, however, retail stores have a significant problem: Most of the occupants at a given instant may be members of the public, rather than employees, and these randomly assembled members of the public will have received no training on what to do in case of earthquake nor have a responsibility toward the store. Providing clear directions to these occupants by the staff is especially important, therefore. With any significant damage, the best course is probably to begin to help occupants exit the building, preferably without any additional sales transactions. (If the power is out, most modern cash registers will not operate in any event). After the public has exited, the store can be locked, spilled items can be cleaned up.

Typical Nonstructural Items - Figure 11 lists representative retail store nonstructural items. The same qualifying statement about the generalizations about priorities stated above applies here as well. Figure 12 illustrates typical nonstructural items.

Typical Retail Store Layout - Figure 13 illustrates a generic retail store layout. The earthquake-relevant features to note are as follows.

The front of the store is where the entrances and exits are located, and these doors are co-located with large display windows. There is very little solid wall at the front, but completely solid walls at the sides and perhaps a wall with only a few openings in it at the rear of the building on the alley. The front of this box is thus "soft" and may rack in an earthquake. Unfortunately, some of the more hazardous nonstructural features are often located at the storefront also.

High Priority for Seismic Evaluation

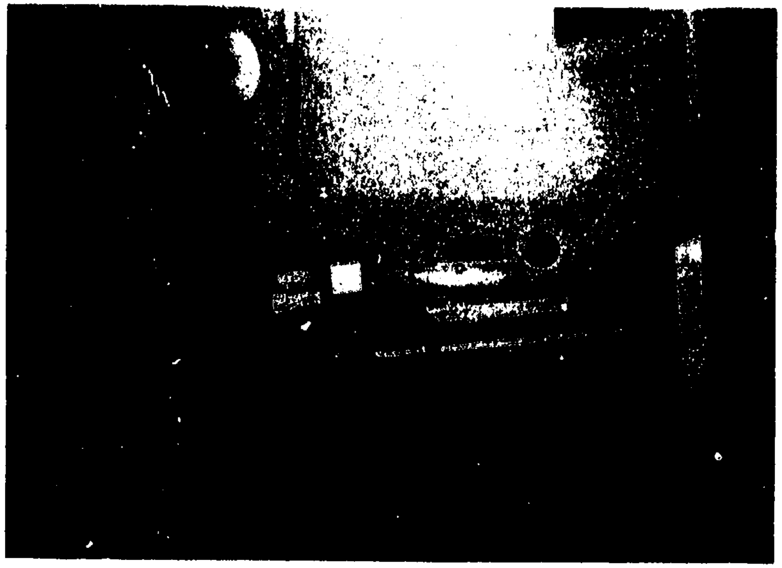
- o Tall, heavy display racks or shelves
- o Tall, heavy storage room racks or shelves
- o Large storefront windows
- o Especially valuable and fragile merchandise
- o Emergency power generator (but not usually present)
- o Heavy overhead objects: light fixtures, large pipes, hanging space heaters
- o Cash register stands

Lesser Priority for Seismic Evaluation

- o Lightweight ceilings
- o Lightweight merchandise, or heavy objects less than 4 or 5 feet off the ground
- o Ordinary office equipment, small file cabinets

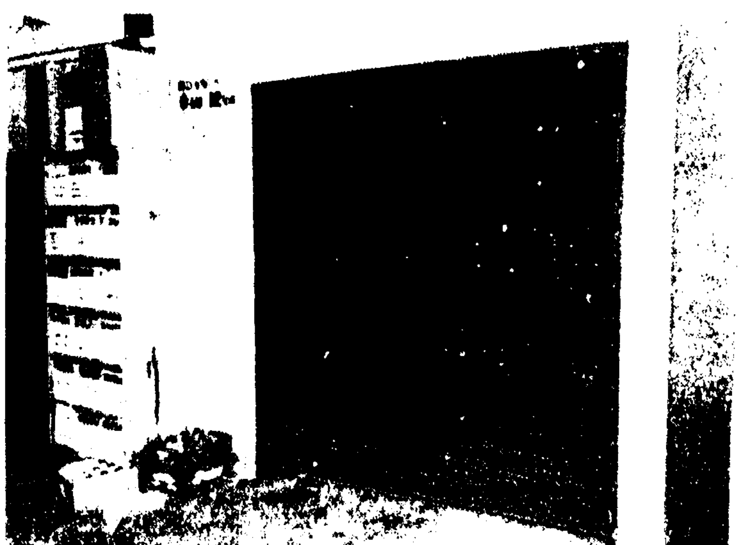
Figure 11
Typical Retail Store Nonstructural Items

47

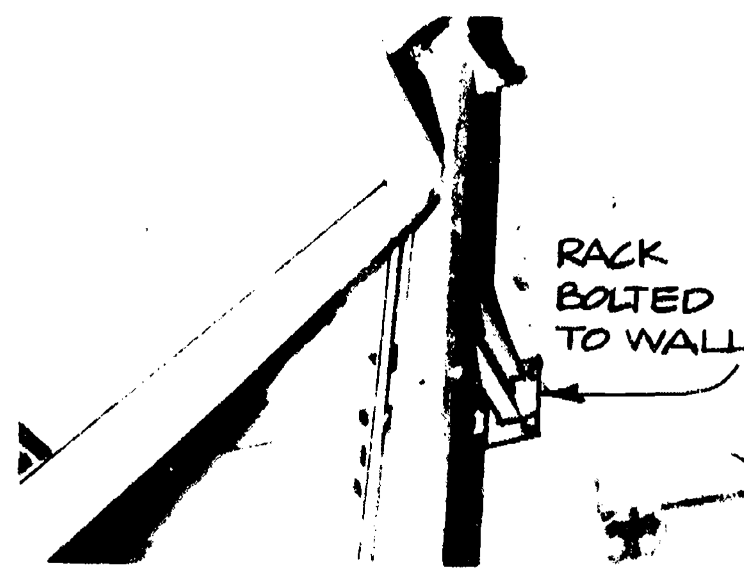


a. Water heater

b. Contents restrained by wire (may not be feasible)



c. Roll-up garage door



d. Tall storage room rack

Figure 12

Typical Scenes of Nonstructural Items in a Retail Store

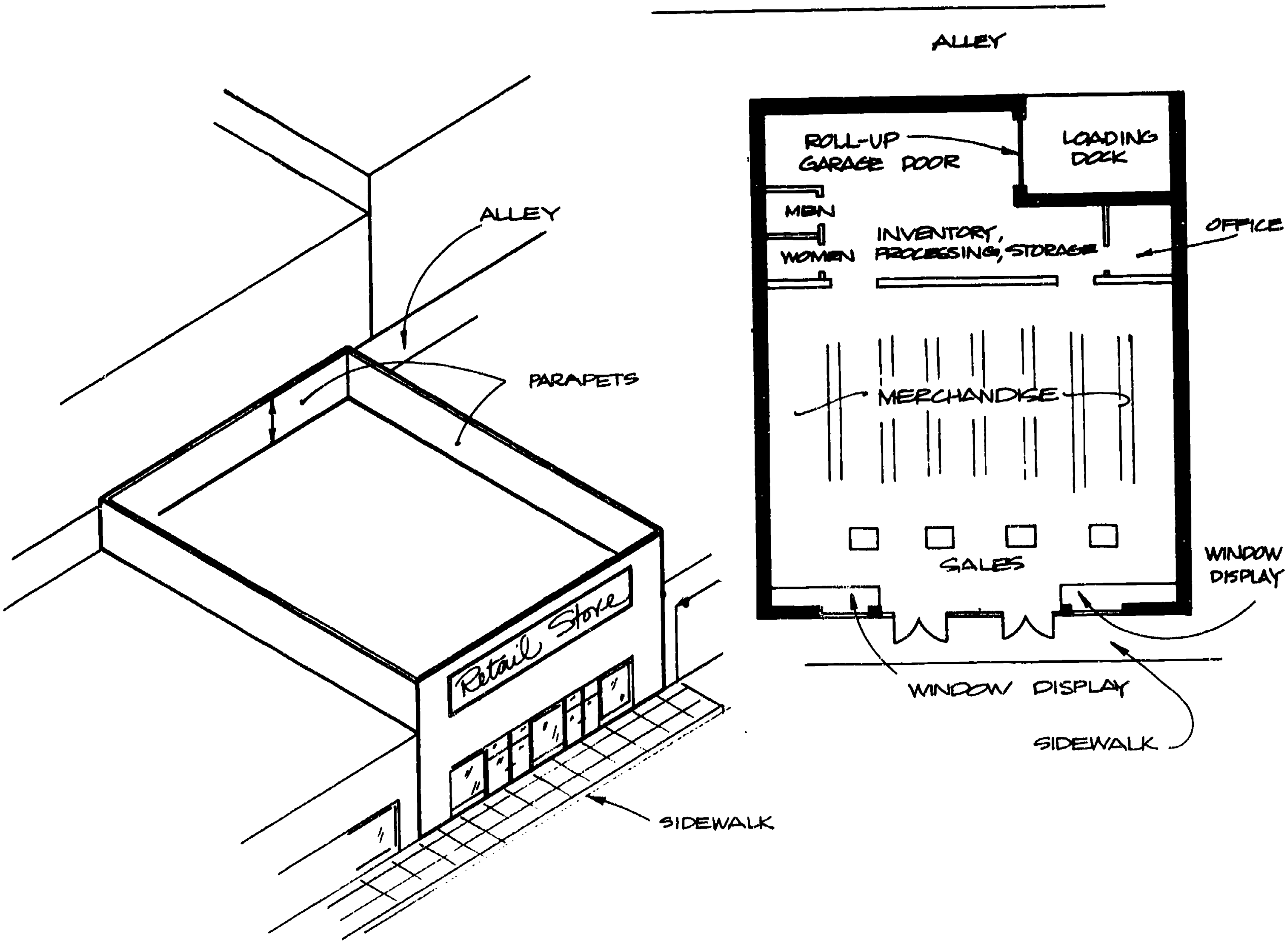


Figure 13

Typical Retail Store Layout

Large storefront windows often break at relatively moderate intensities of shaking. Only in newer stores will some windows that are immediately next to doors or extend down almost to the ground, be tempered glass (which breaks into rounded rather than sharp fragments). In older masonry buildings, there will probably be brickwork supported over the storefront portion of the building that is damage prone at just a moderate level of shaking. Parapets around the roof on older masonry buildings are especially easily dislodged by earthquakes. Signs may occasionally break off and fall in earthquakes also. For these reasons, the most hazardous location is probably the sidewalk, where glass, bricks and/or stucco, signs, or a combination of these kinds of debris may fall. Training employees not to run out of the building and to instead just take cover under a table, by a check-out stand, etc., is probably the best emergency planning means of dealing with these hazards, while retrofit construction techniques can help prevent the damage from occurring in the first place.

The majority of the floor space is typically open plan or subdivided with only display cases and occasional display partitions. Cash registers in department stores are located throughout the area used for merchandise display, while in supermarkets and most small stores they are located at the front.

At the rear of the store is the area used by employees for inventory storage and stocking, clerical and managerial activities in an office or offices, rest rooms, and a mechanical room for air conditioning and other equipment. Supermarkets will have refrigeration equipment for food cooling, while small retail stores will have only a small heater or heater-air conditioner and a small water heater. Most retail stores do not have an emergency power generator.

Truck deliveries will probably occur at the rear of the store, relying on a loading dock and roll-up overhead door for access of goods into the building. These types of doors have jammed in past earthquakes, though they can usually be opened manually if several people work strenuously on the problem. There should be pull chains or other manual opening controls because the power may go out. Goods are typically stored in a rear room on tall racks.

Low-rise Government Services Building

In this type of building most of the employees are engaged in office operations similar to those in a commercial office building, although record storage may be a major function in centralized areas, and more members of the public may be in the building at a given moment. Record storage generally implies tall shelving or cabinetry. Large computer areas may be found, often with raised computer floors.

Special conditions and unusually essential functions are found in fire, police, and emergency operations facilities if located in a multi-purpose local government building. This topic is largely outside the scope of this booklet, except to note that the earthquake vulnerability of nonstructural items essential for post-earthquake operations, such as teletypes, radios, computers, or stored medical supplies, should be taken even more seriously in these kinds of departments.

Typical Nonstructural Items - Figure 14 provides a list of these similarly as for the other two types of buildings discussed earlier and photographic examples are shown in Figure 15.

Typical Government Building Layout - Figure 16 illustrates the layout of a representative local govern-

High Priority for Seismic Evaluation

- Heavy overhead objects: pipes, light fixtures, air diffusers
- Speakers in hearing-meeting rooms
- Emergency power generator, battery-powered lights
- Tall, heavy storage racks
- Emergency supply inventory (water, medicine, food, etc.)

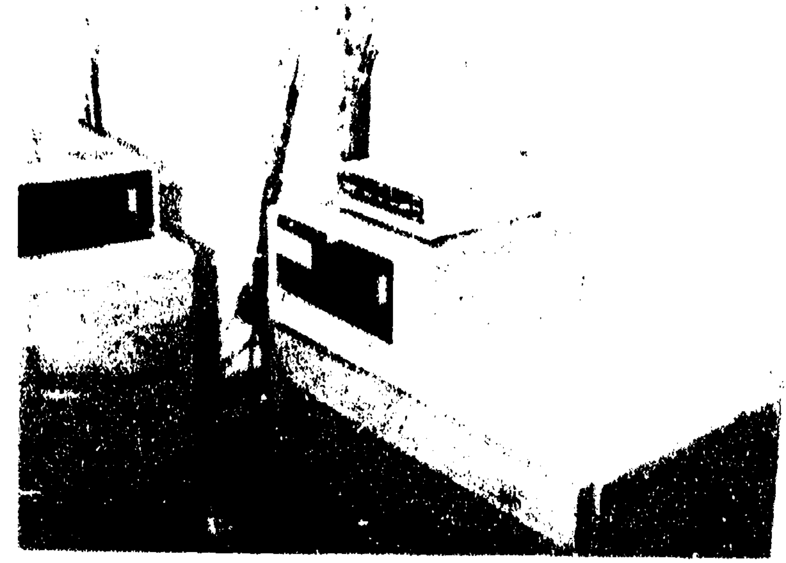
Lesser Priority for Seismic Evaluation

- Lightweight ceilings
- Partitions
- Ordinary office equipment

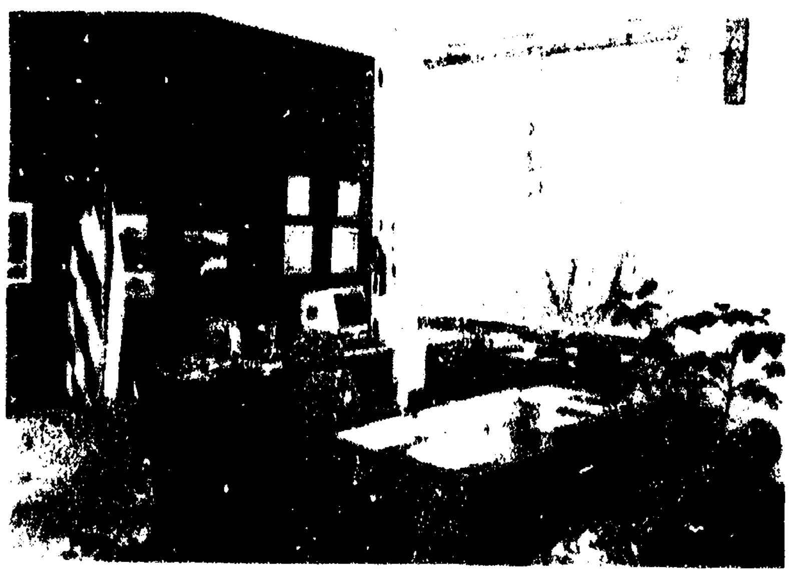
Figure 14
Typical Government Building
Nonstructural Items

54

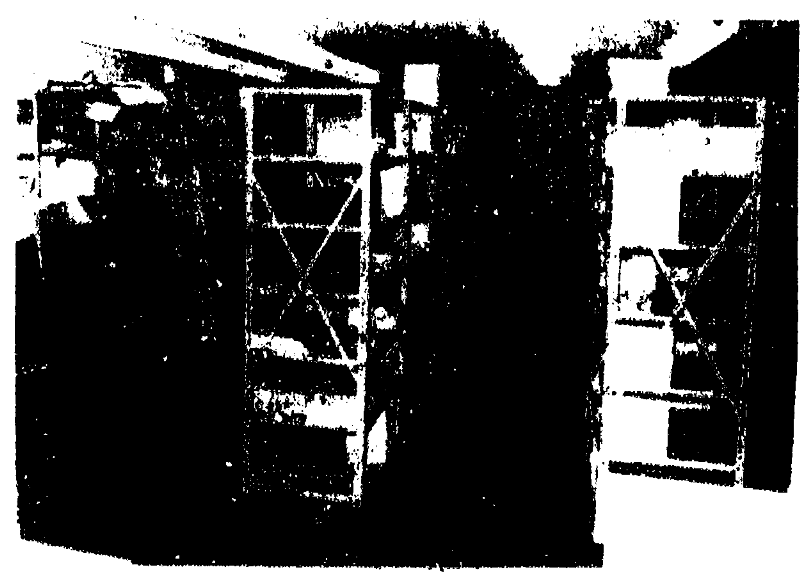
a. Battery-powered emergency lights



b. Computer telecommunications



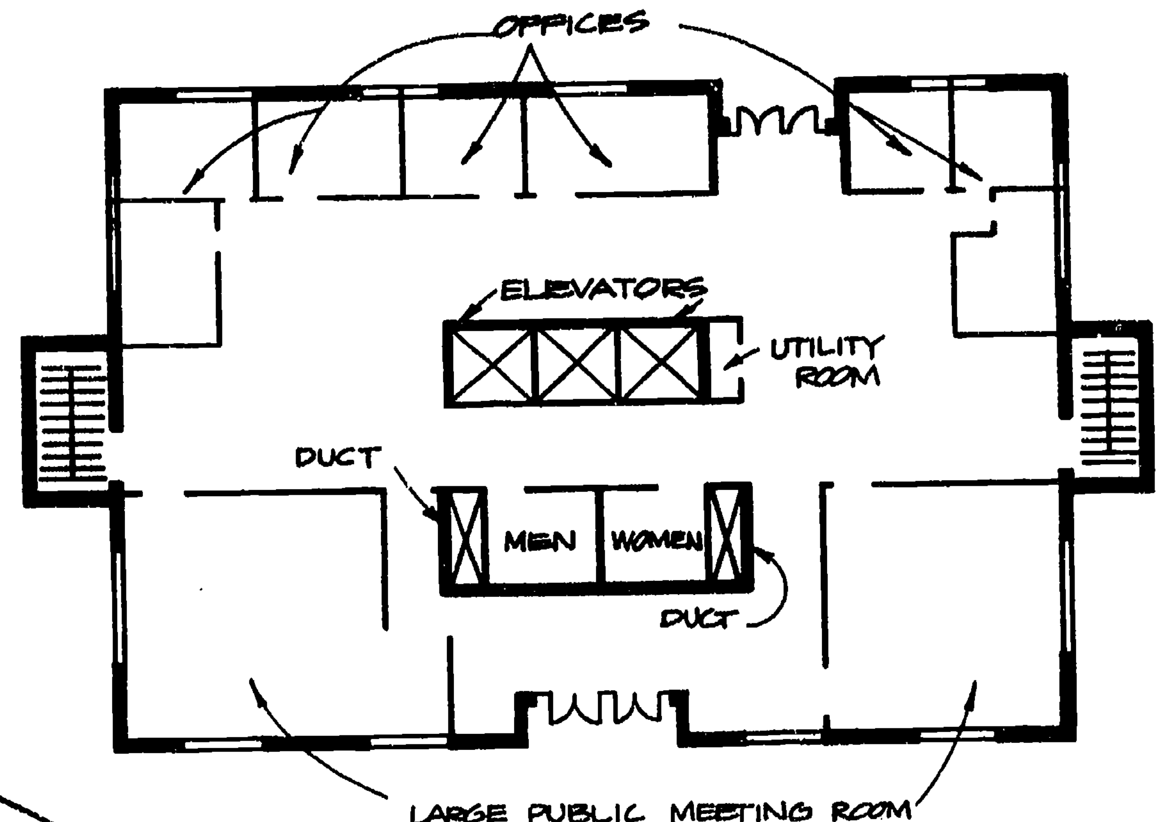
c. Executive office



d. Storage room

Figure 15

Typical Scenes of Nonstructural Items In a Government Building



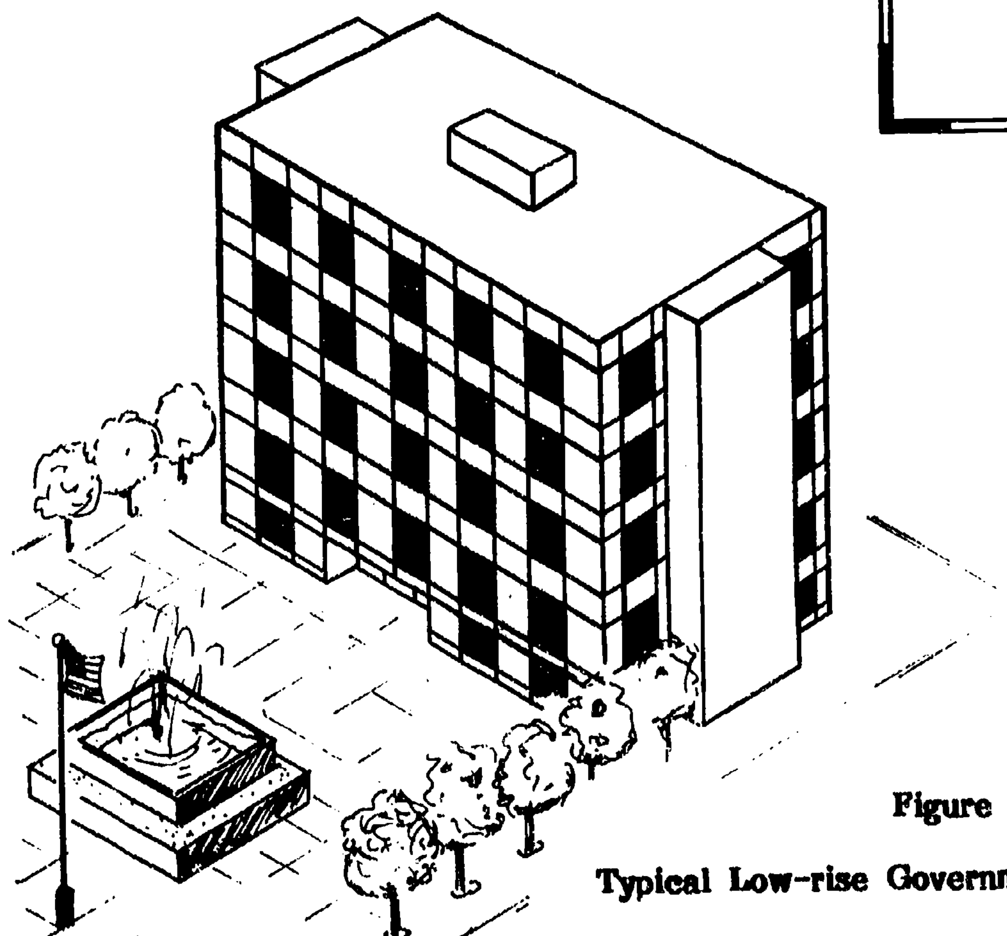


Figure 16

Typical Low-rise Government Building Layout

ment services building. It may be multistory, but will probably only be a few stories in height rather than 10, 20, or 30 stories tall as for commercial office buildings. Tall government buildings will share many of the characteristics of the tall office towers discussed at the beginning of this chapter. There may be a large plaza, park, parking lot, or other open area around the building, which provides an ideal place for re-grouping occupants if there is a building evacuation. The large public assembly rooms are not usually found in a commercial office or retail building.

Meeting and hearing rooms or law courtrooms may be found in multi-purpose government buildings, and these large assembly rooms differentiate this type of building from the typical commercial office building. Since there will almost always be a judge, commission chair, manager, or other person of leadership in charge of large gatherings, these individuals should be instructed in how to respond should an earthquake occur in a room filled with people. The best advice is to direct people to kneel down between the seats right where they are: This provides the best protection from the occasional falling piece of ceiling, and it helps prevent a panicky run for the exits which could injure people by pushing and falling.

3. Individual Nonstructural Items: Vulnerability and Countermeasures

How will a specific nonstructural item perform in an earthquake? How do you know what your potential problems are? In this chapter, typical nonstructural items are described in terms of their earthquake damageability relative to different intensities of shaking. Enough categories of nonstructural portions of buildings have been provided to allow for an effective initial review of most office, retail, and government buildings.

These damage estimates are derived from analyses using COUNTERQUAKE, a computer program developed by Scientific Service, Inc. under a National Science Foundation grant. COUNTERQUAKE individually analyzes nonstructural components within different types of buildings and on different sites. Simplifying assumptions have been made here to apply the method to typical rather than specific actual cases, and in any event, estimates of future earthquake damage to either the structural or nonstructural portions of a building are only just that -- estimates -- regardless of the method used. In most cases, the approximations provided here are adequate for purposes of initially determining vulnerabilities. In some cases, more detailed analyses than provided in this general purpose booklet should be obtained from a consultant or in-house engineer if the potential risks are great.

The high-moderate-low statements of life safety and outage risks are self-explanatory. The percentages of replacement cost which state the property losses can be multiplied by the cost of replacing a given category of items to produce an estimated loss figure.

In the charts in this chapter, the most promising countermeasures for protecting each item from earthquake damage are provided. In some cases these anchorage, restraint, or other retrofit measures can be applied as shown. In other cases, the method might require adaptation to a particular case, or a design professional's assistance would be required to develop particular designs.

The cost estimates can only be considered rough guides, since it is not possible to account for all of the specific differences in construction conditions found in buildings nor to allow for the variation in cost between different contractors during changing construction market conditions or between in-house labor versus outside contractor costs. The costs do not include any engineering or architecture services that may be required.

The effects estimated for each component are essentially only inertial effects as discussed in Chapter 1, except where noted. The imposed distortion problem is also significant, but it requires a knowledge of the detailed characteristics of each building to intelligently estimate whether problems are present or not. Some buildings will sway one inch, others two inches, under the same earthquake shaking and loading, for example, and the mountings of some windows can tolerate considerable racking of the surrounding frame while others are much more locked-in. In general, there are few practical means of retrofitting built-in nonstructural portions of buildings, such as windows or partitions, to protect them from cracking when the building sways and distorts, while there are usually many feasible ways of protecting freestanding objects. For new construction, the problem of nonstructural damage caused by distortion of the structure should be given thorough attention by architect and engineer, however, because in the design stage there is great potential for dealing with this problem.

Intensities - Will your building experience the light, moderate, or severe intensity of shaking listed in these charts? As suggested in Chapter 1, for most of California, the severe category of intensity is a valid assumption, and if any of the effects associated with this level of shaking would be disastrous, further attention is warranted. If located in California's Central Valley or other next-to-highest seismic zone areas, the moderate intensity is appropriate, though it is possible to think of examples which do not follow this rule: A very essential computer installation, for example, (or essential types of buildings like hospitals and fire stations) would be designed to stricter criteria even if not located in the highest seismic zone.

Flexible buildings sway more, and hence impose a greater change of shape or distortion on partitions and other rigid built-in nonstructural elements. They can also experience more violent whiplash motions, and so they are more damage prone from our nonstructural point of view. The following charts have been prepared with typical low-rise, bearing wall (shear wall) buildings in mind, and these structures are relatively stiff. If these stiff buildings move as much as a frame structure, it is only at the point of major structural damage where their walls or floors would be extensively cracked.

For the upper stories of buildings about eight to ten stories or taller, for lower frame buildings without any structural walls, and for the open-faced storefront facades of buildings in which solid structural walls are only located elsewhere, the light-moderate-severe intensity levels shown in the charts should be increased almost one notch: A light intensity of ground motion can be assumed to cause a moderate intensity up in the flexible building, or a moderate ground intensity can be assumed to be increased to severe. If a flexible building is located where severe intensity is already presumed to be the future intensity, there is a greater chance that the corresponding damage shown in the chart will occur or will occur to more components.

The photographs illustrating actual instances of damage to each type of nonstructural item provide a graphic explanation of the damage that could occur. These photos, in addition to illustrating potential problems, also serve to prove that these problems have actually occurred and can appear in the future after other earthquakes in urban areas.

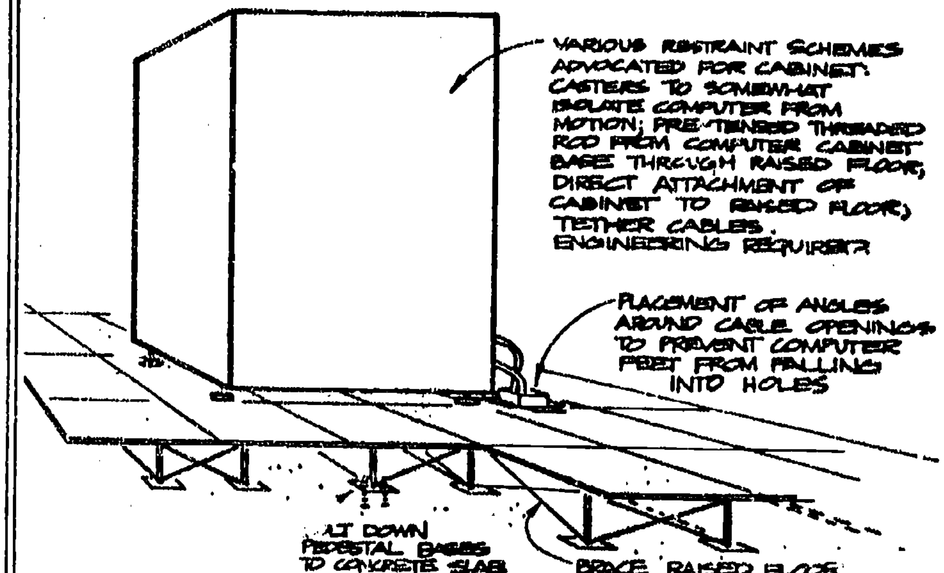
Chapter 4 provides guidance on how to tabulate and use the information contained in the charts of this chapter.

LARGE COMPUTERS AND OFFICE MACHINES

DAMAGE EXAMPLE

earthquake: 1978 Sendai, Japan
credit: Anshel Schiff

PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: Floor alone: $2–5/per sq. ft. Cabinet restraint cost varies.

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▦
LIGHT	jiggling of tall equipment; misalignment	low	0–10%	low
MODERATE	occasional shifting of equipment; some chance of damage	low	10–30%	high
SEVERE	overturning of most tall equipment	mod	30–100%	high

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▦
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	equipment intact; chance of some damage due to slight movement vis-a-vis connections	low	0–10%	mod

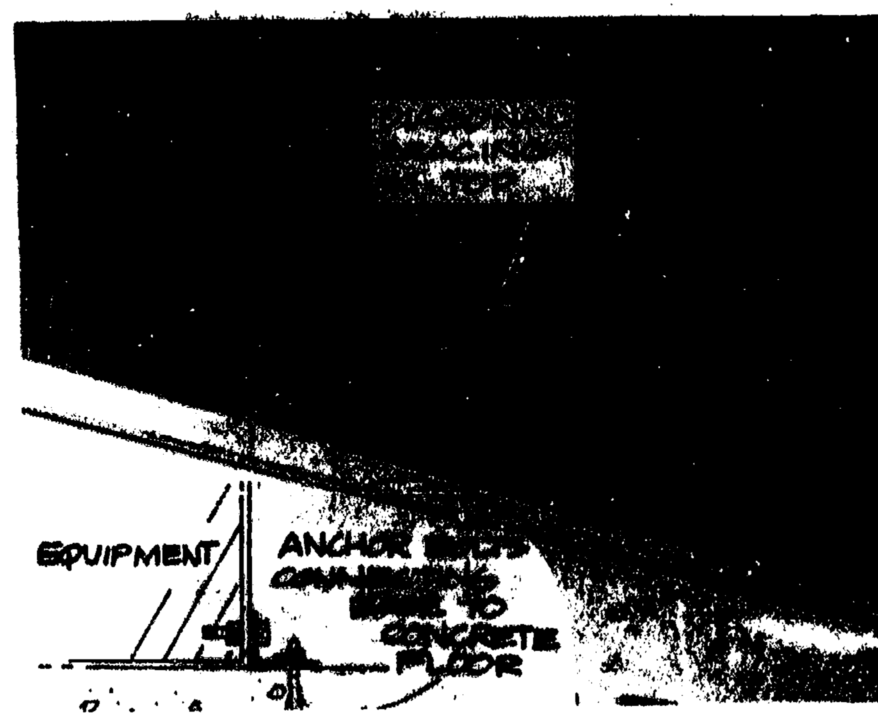
✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED ▦ POST-EARTHQUAKE OUTAGE

ELECTRICAL EQUIPMENT

DAMAGE EXAMPLE

earthquake: 1971 San Fernando
credit: John F. Meehan

PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: $50-100 each "refrigerator-sized" piece of equipment

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	Outage
LIGHT	no damage	low	0-5%	low
MODERATE	swaying of tall equipment	mod	5-20%	high
SEVERE	overturning of tall equipment	mod	20-80%	high

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	Outage
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	no damage to anchored equipment; some damage to distribution system	low	0-10%	low

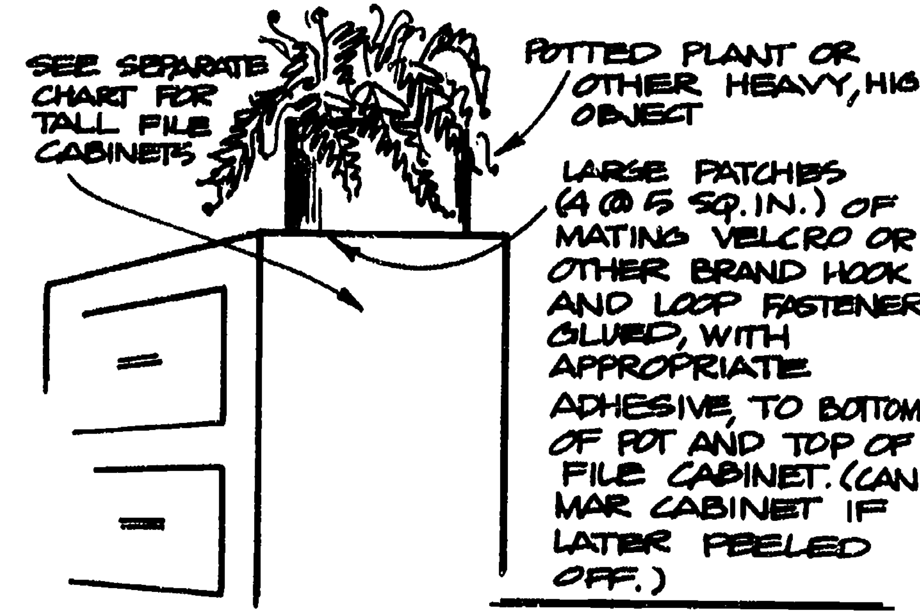
✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED [outage icon] POST-EARTHQUAKE OUTAGE

MISCELLANEOUS OFFICE FURNISHINGS

DAMAGE EXAMPLE

earthquake: 1979 Santa Barbara
credit: Larry Parsons/Health and Safety, UCSB

PROTECTIVE COUNTERMEASURE



CHAIRS, DESKS AND TABLES HAVE ONLY VERY RARELY OVERTURNED IN EARTHQUAKES; COUNTERS AND CASEWORK SHOULD BE ANCHORED, HOWEVER.

APPROXIMATE COST: $1.50 materials plus 15 minutes labor

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	(outage)
LIGHT	no damage	low	0–5%	low
MODERATE	no damage	low	5–20%	low
SEVERE	tipover or shifting of a few top-heavy and narrow items	mod	20–50%	mod

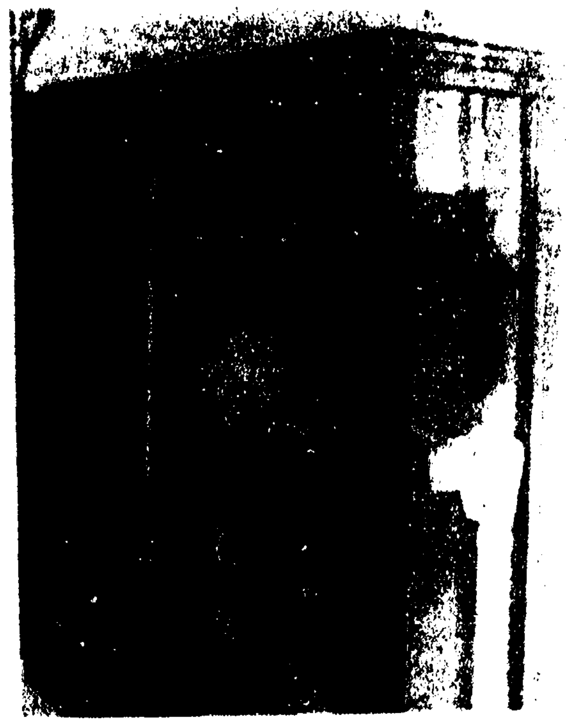
UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	(outage)
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	occasional tipover of small items; furniture slides up to a few inches	low	0–10%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED (outage icon) POST-EARTHQUAKE OUTAGE

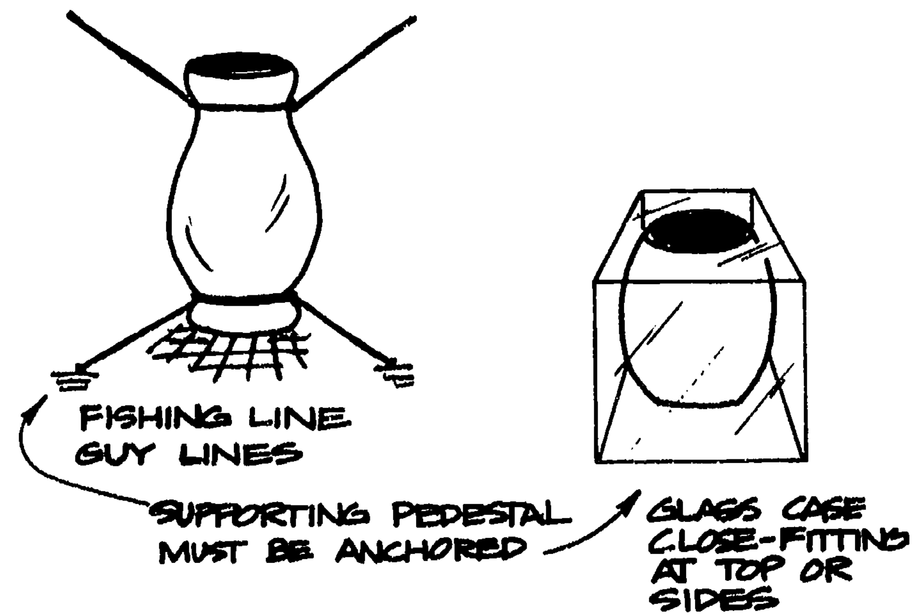
FRAGILE ARTWORK

DAMAGE EXAMPLE



earthquake: 1906 San Francisco
copyright: Stanford University Archives

PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: varies; generally less than $100 per item

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▦
LIGHT	damage only to occasional tall object	low	0-20%	low
MODERATE	items which can roll or tipover damaged; cases and stands generally stable unless 1.5 to 2 times taller than wide	low	20-50%	low
SEVERE	entire cases or stands may tipover	mod	50-100%	mod

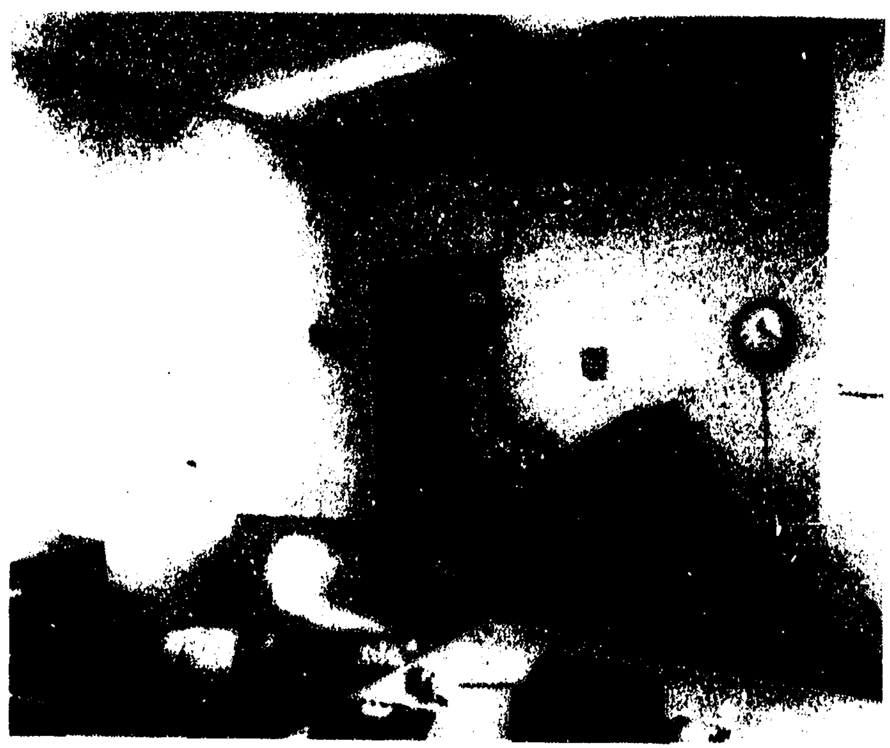
UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▦
LIGHT	no damage	low	0%	low
MODERATE	some misalignment but small chance of damage	low	0-5%	low
SEVERE	some chance of damage since complete restraint may be infeasible	low	0-10%	low

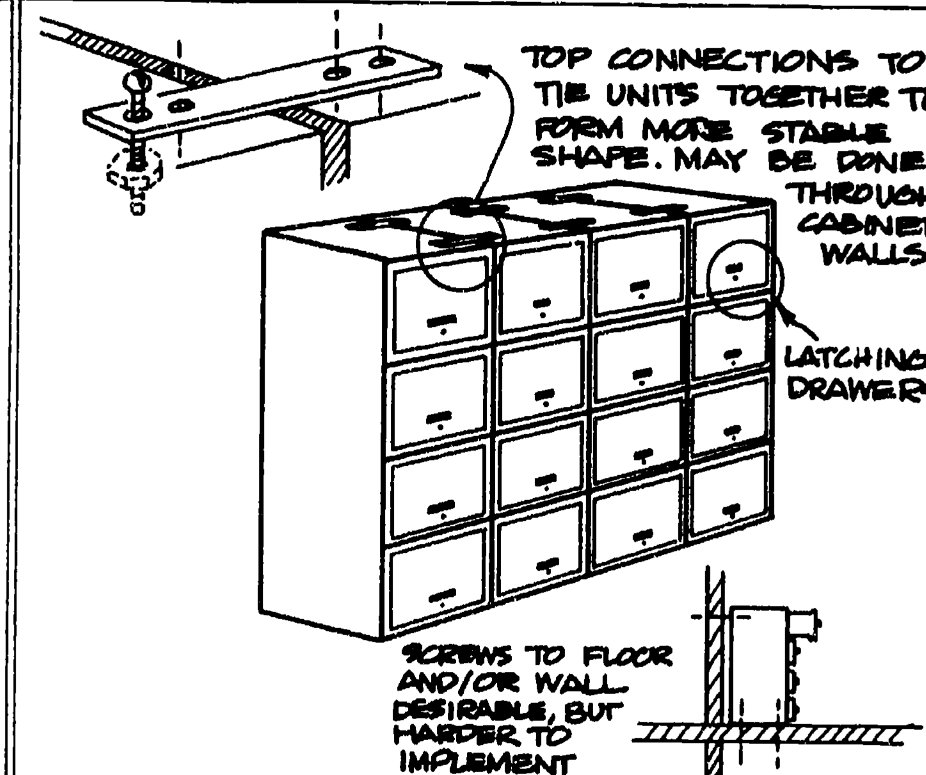
✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED ▦ POST-EARTHQUAKE OUTAGE

TALL FILE CABINETS

DAMAGE EXAMPLE	PROTECTIVE COUNTERMEASURE



earthquake: 1979 Imperial Valley, California
credit: BSD, Inc.



APPROXIMATE COST: $5 per pair of cabinets; latching models standard

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS		$	
LIGHT	no damage	low	0–5%	low
MODERATE	occasional tipover if drawers unlatched and if top heavy	mod	5–20%	mod
SEVERE	tipover of most tall cabinets	mod	20–50%	high

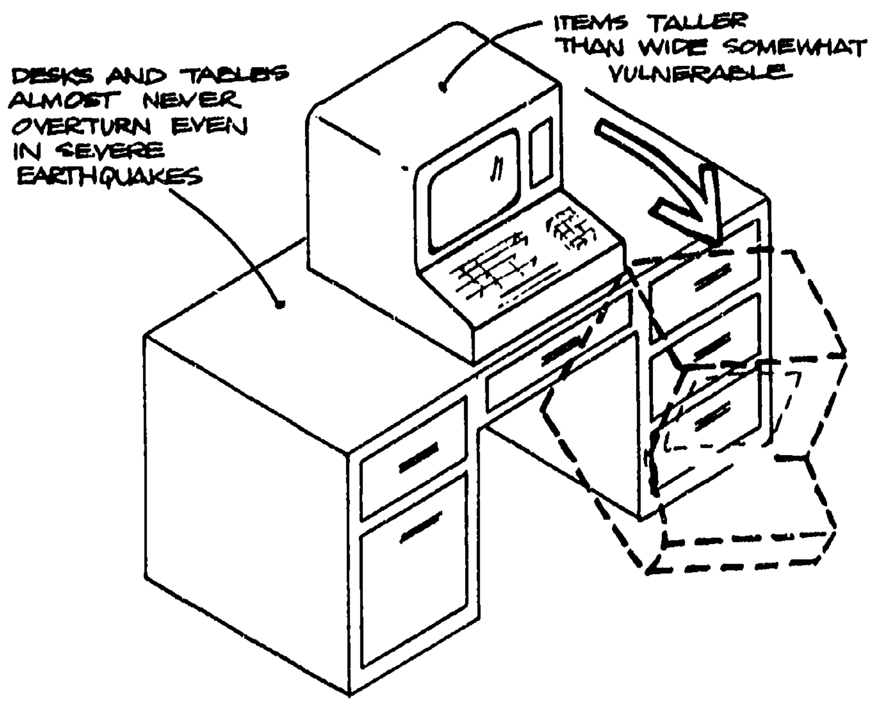
UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS		$	
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	damage limited to spillage of occasional individual unlatched drawer	low	0–10%	low

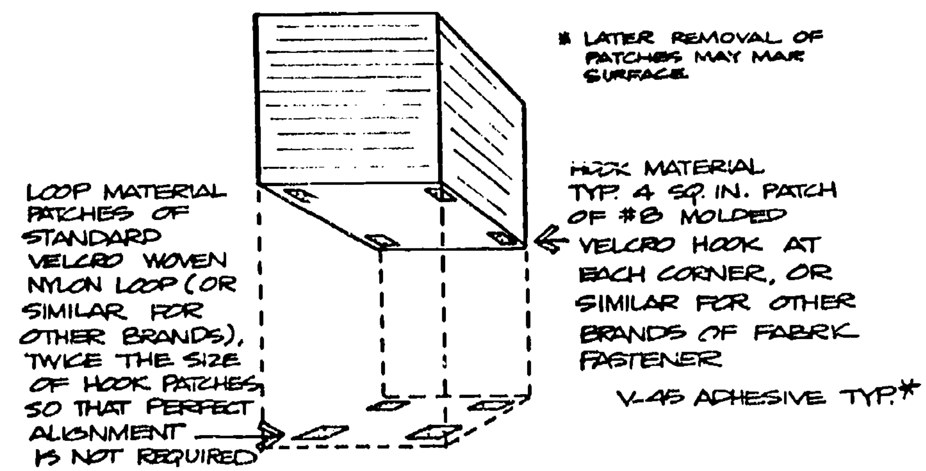
LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED   POST–EARTHQUAKE OUTAGE

DESK TOP COMPUTERS AND OFFICE EQUIPMENT

DAMAGE EXAMPLE



PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: $1.50 per item material plus 15 minutes labor

EXISTING VULNERABILITY

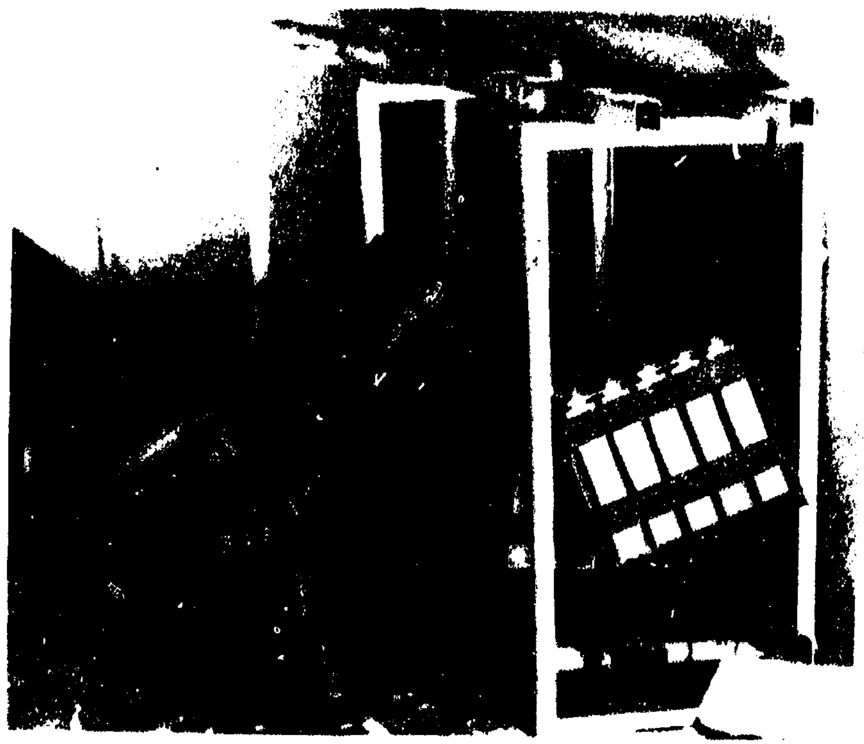
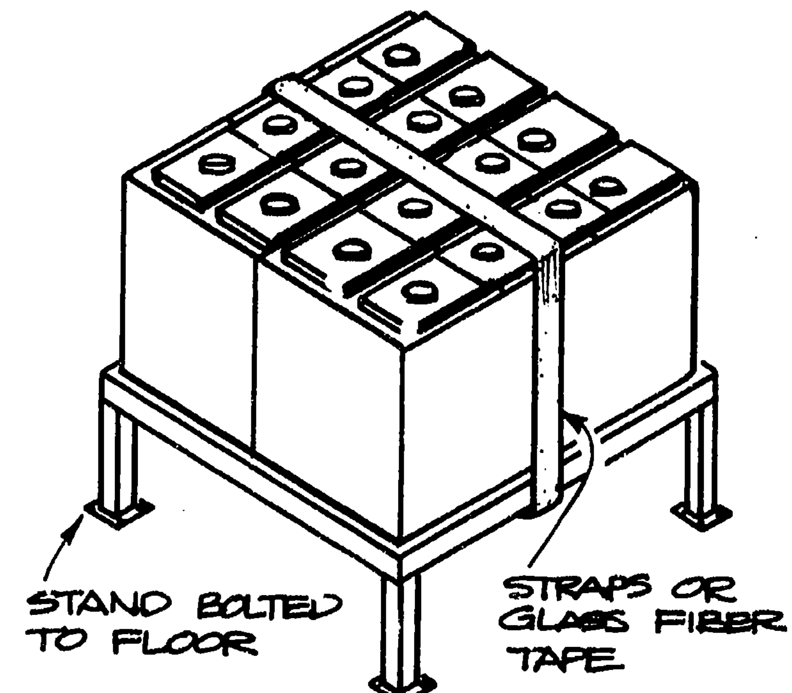
SHAKING INTENSITY	EFFECTS	LIFE SAFETY HAZARD	$	POST-EARTHQUAKE OUTAGE
LIGHT	no damage	low	0–10%	low
MODERATE	shifting of equipment	low	10–20%	mod
SEVERE	some equipment falls to floor	mod	20–80%	high

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	LIFE SAFETY HAZARD	$	POST-EARTHQUAKE OUTAGE
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	downtime more likely to be due to electrical outage or building damage than equipment damage	low	0–10%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED   POST–EARTHQUAKE OUTAGE

EMERGENCY POWER GENERATORS

DAMAGE EXAMPLE	PROTECTIVE COUNTERMEASURE
	
	FOR GENERATOR ANCHORAGE, SEE HEATING-VENTILATING-AIR CONDITIONING EQUIPMENT CHART.
earthquake: 1971 San Fernando credit: John F. Meehan	APPROXIMATE COST: $10 per rack for strapping $50 for bolting

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▦
LIGHT	slight chance of piping connection break	low	0–5%	mod
MODERATE	slight shifting of equipment; batteries slide	low	5–20%	high
SEVERE	lurching of generator off supports; batteries fall	mod	20–50%	high

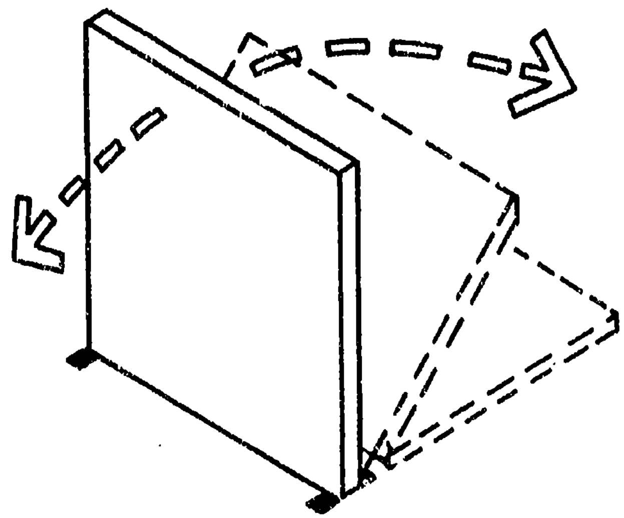
UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▦
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	damage to rest of electrical system more likely than generator damage	low	0–5%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED ▦ POST-EARTHQUAKE OUTAGE

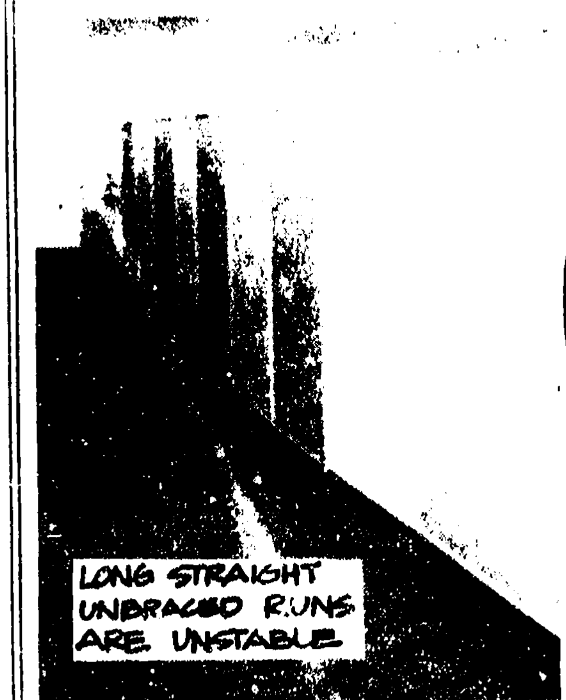
FREESTANDING MOVABLE PARTITIONS

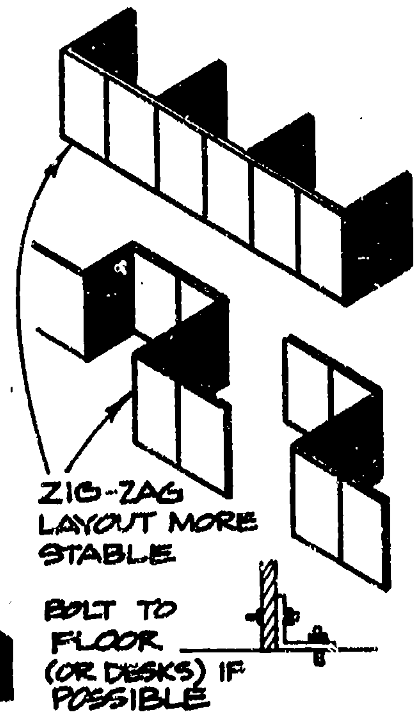
DAMAGE EXAMPLE



FREESTANDING PARTITIONS MAY TIPOVER PERPENDICULAR TO THEIR LENGTH IF NOT ATTACHED TO DESKS OR ANCHORED TO FLOOR

PROTECTIVE COUNTERMEASURE





APPROXIMATE COST: none for zig-zag layout; $10-20 per panel for bolting

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS		$	
LIGHT	no damage	low	0-5%	low
MODERATE	occasional tipover of taller partitions without nearby restraint	low	5-10%	low
SEVERE	tipover of most partitions	mod	10-20%	low

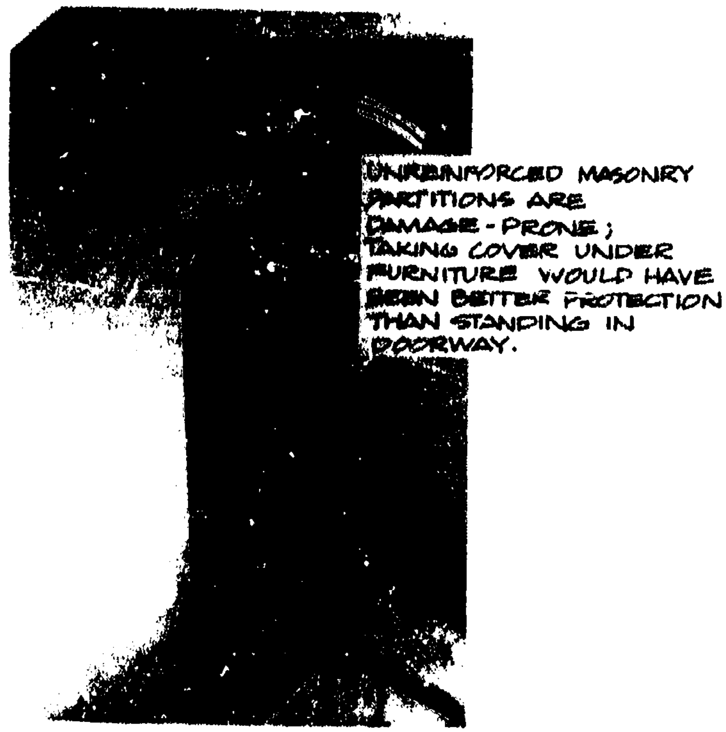
UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS		$	
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	slight chance of occasional panel tipover	low	0-5%	low

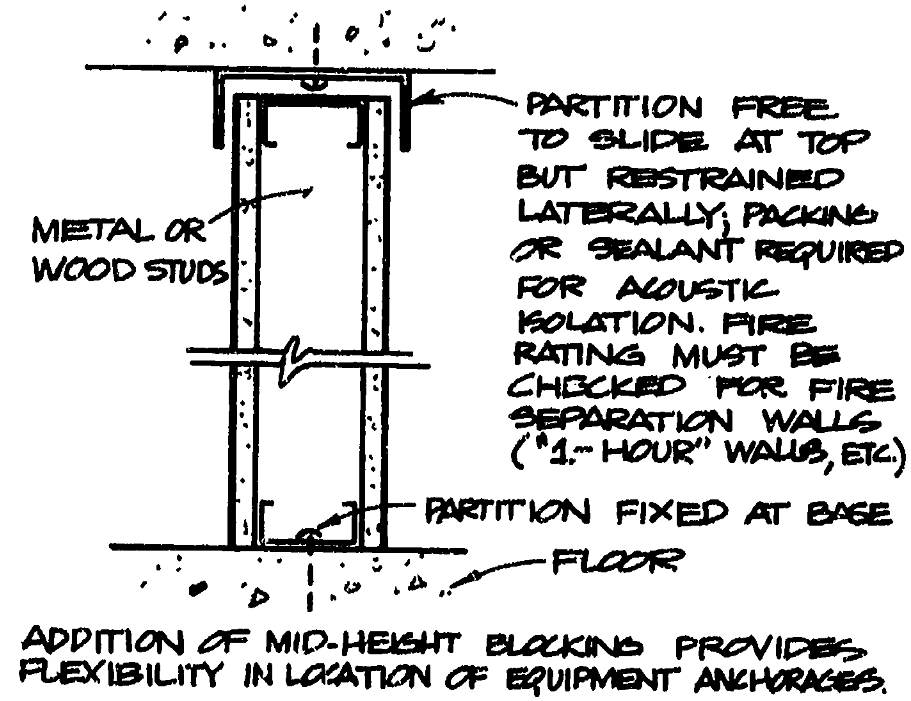
LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED   POST-EARTHQUAKE OUTAGE

BUILT-IN PARTITIONS

DAMAGE EXAMPLE	PROTECTIVE COUNTERMEASURE



earthquake: 1972 Nicaragua
credit: John F. Meehan



APPROXIMATE COST: varies according to design

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	(outage)
LIGHT	no damage	low	0–5%	low
MODERATE	occasional cracking	low	5–20%	low
SEVERE	extensive cracking; occasional falling over if structure is severely damaged	low	20–100%	mod

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	(outage)
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0–5%	low
SEVERE	only occasional cracking unless building is severely damaged	low	5–20%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED (chart) POST–EARTHQUAKE OUTAGE

WINDOWS

DAMAGE EXAMPLE	PROTECTIVE COUNTERMEASURE

earthquake: 1971 San Fernando
credit: John F. Meehan

① IF TINTED ADHESIVE SOLAR FILM DESIRABLE TO REDUCE LIGHT AND HEAT, IT WILL ALSO HELP HOLD TOGETHER FRAGMENTS OF ANY PANES THAT CRACK IN EARTHQUAKE.

② USE OF LAMINATED GLASS FOR STOREFRONTS REDUCES SEISMIC AS WELL AS BURGLARY-VANDALISM RISKS.

③ IN NEW CONSTRUCTION, STIFFER BUILDINGS WITH GREATER THAN STANDARD EDGE CLEARANCES (TYP. GREATER THAN 1/4" ALL ROUND) DESIRABLE.

④ SMALLER, OPERABLE, AND WOODEN FRAMED WINDOWS TOLERATE MORE DRIFT.

APPROXIMATE COST: solar film: $1 per sq. ft., including installation

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	OUTAGE
LIGHT	no damage	low	0–5%	low
MODERATE	cracking of large windows	mod	5–50%	mod
SEVERE	shattering of glass; pieces thrown both directions from pane; small windows and those allowing for movement undamaged	high	50–100%	high

UPGRADED VULNERABILITY

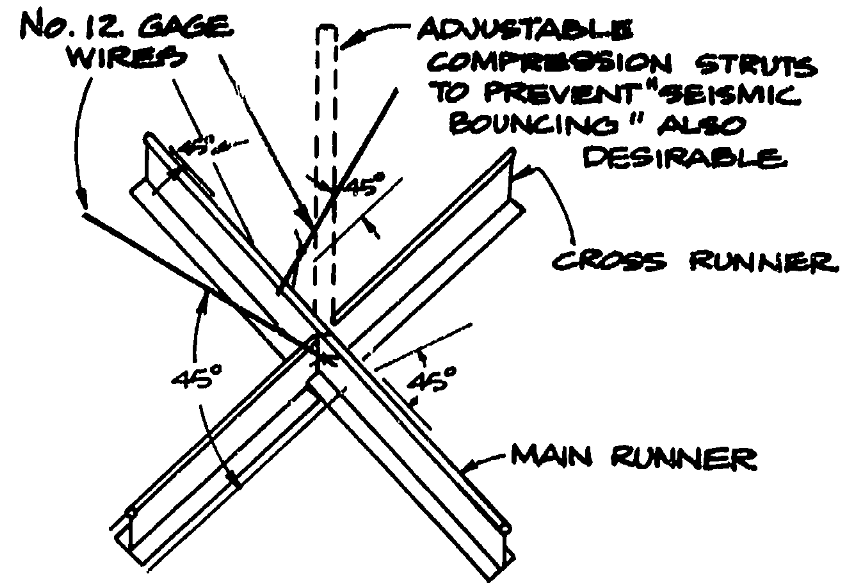
SHAKING INTENSITY	EFFECTS	✚	$	OUTAGE
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	cracking of large windows if building severely damaged	low	0–20%	mod

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED   POST-EARTHQUAKE OUTAGE

SUSPENDED CEILINGS

DAMAGE EXAMPLE	PROTECTIVE COUNTERMEASURE

earthquake: 1972 Nicaragua
credit: John F. Meehan



4-WAY DIAGONAL BRACING EVERY 12 FT ON MAIN RUNNERS, AND WITHIN 4 FT OF WALLS

APPROXIMATE COST: $20 per sq. ft.

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	(outage)
LIGHT	only occasional dislodged tile	low	0-5%	low
MODERATE	falling of some of ceiling, especially at perimeter and in large rooms	mod	5-20%	mod
SEVERE	falling of most or all of ceiling tiles, as well as some ceiling mounted equipment and ceiling frame	mod	20-100%	mod

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	(outage)
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	slight chance of occasional dislodged tile	low	0-5%	low

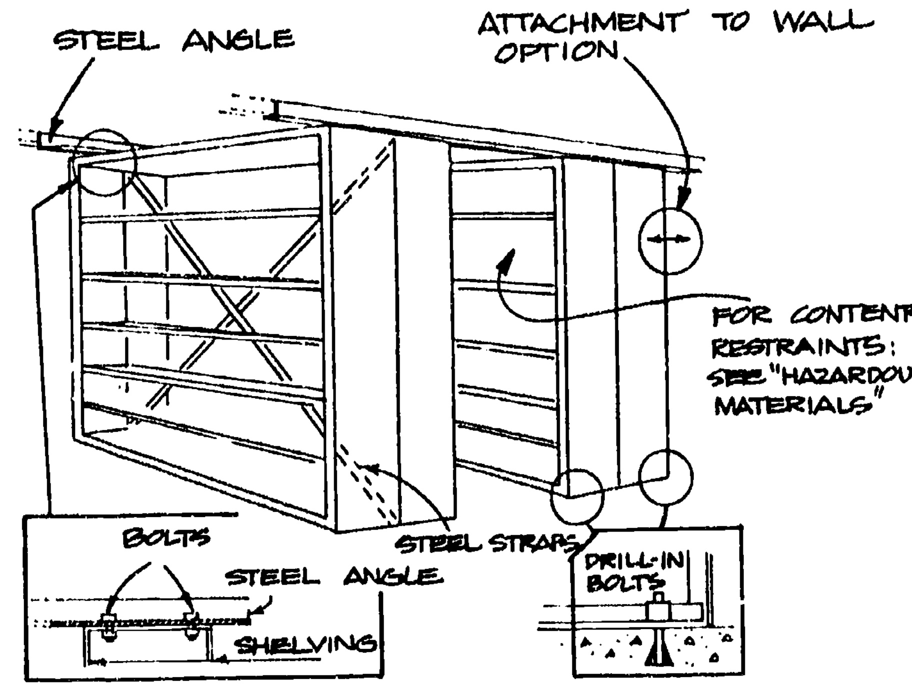
✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED (outage) POST-EARTHQUAKE OUTAGE

TALL SHELVING

DAMAGE EXAMPLE

earthquake: 1972 Nicaragua
credit: John F. Meehan

PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: $5 per lineal foot of shelving

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	LIFE SAFETY HAZARD	$	OUTAGE
LIGHT	occasional tall heavy shelf tips from distant earthquake	low	0–5%	low
MODERATE	overturning of some of heaviest shelving	mod	5–20%	mod
SEVERE	overturning of most shelving	high	20–80%	high

UPGRADED VULNERABILITY

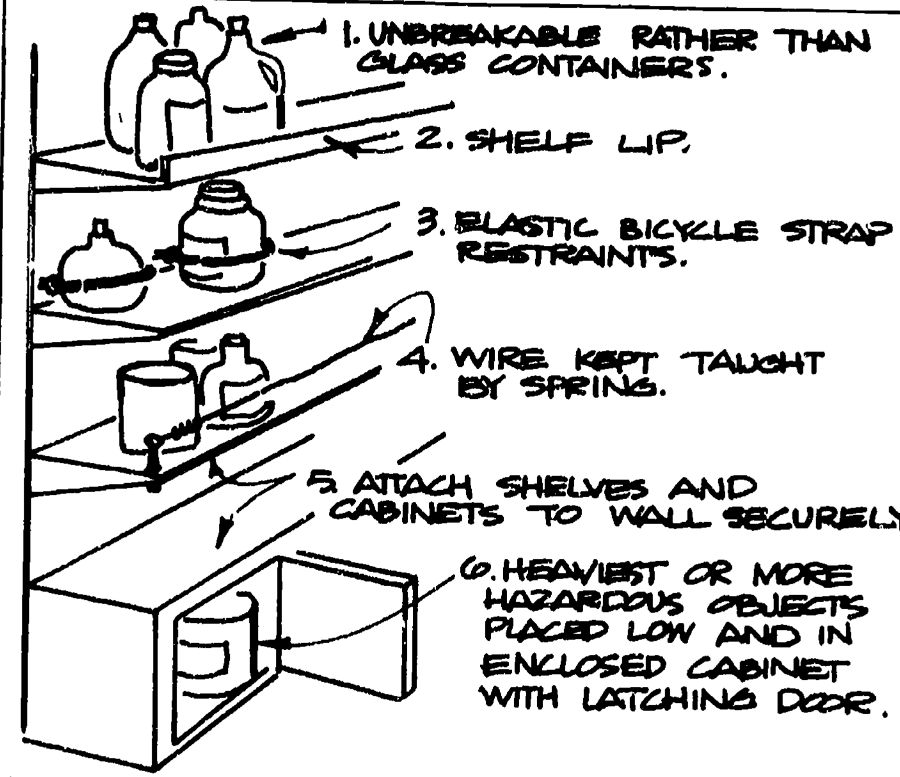
SHAKING INTENSITY	EFFECTS	LIFE SAFETY HAZARD	$	OUTAGE
LIGHT	none	low	0%	low
MODERATE	some of unrestrained contents fall out	low	0–10%	low
SEVERE	unlikely shelving will be damaged; half of unrestrained contents fall out; almost none of restrained contents	low	10–50%	mod

LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED POST–EARTHQUAKE OUTAGE

CONTAINERS OF HAZARDOUS MATERIALS

DAMAGE EXAMPLE	PROTECTIVE COUNTERMEASURE

earthquake: 1971 San Fernando
credit: Scientific Service, Inc.



APPROXIMATE COST: 1. no cost; 2. $.50/lin. ft.; 3. $2.50 ea.; 4. $.50/ft.; 5. $1/ft.; 6. no cost

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▦
LIGHT	slight chance of spill; due to sloshing	mod	0–20%	mod
MODERATE	good chance of spill; some containers fall, pipes leak	high	20–50%	high
SEVERE	large tanks leak ; falling containers, broken piping; damage also to adjacent items	high	50–100%	high

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▦
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0–5%	low
SEVERE	small chance of spill in distribution system; no spill of containers	mod	5–10%	mod

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED ▦ POST–EARTHQUAKE OUTAGE

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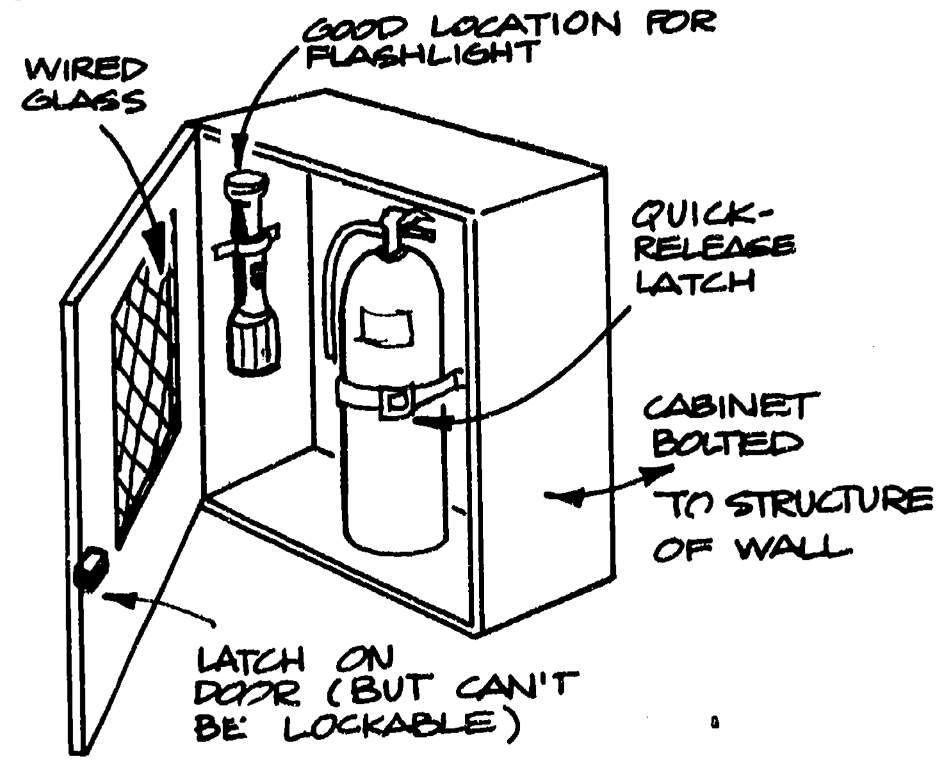
FIRE EXTINGUISHERS

DAMAGE EXAMPLE

earthquake: 1979 Santa Barbara
credit: Larry Parsons/Health and Safety, UCSB

PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: $50-100 extra

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	Life Safety Hazard	$	Post-Earthquake Outage
LIGHT	small chance extinguisher will tip	low	0-10%	low
MODERATE	good chance that extinguisher will tip and fall out	low	10-20%	mod
SEVERE	poorly connected cabinet may rip loose, as well as falling of contents	low	20-50%	high

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	Life Safety Hazard	$	Post-Earthquake Outage
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	no damage	low	0%	low

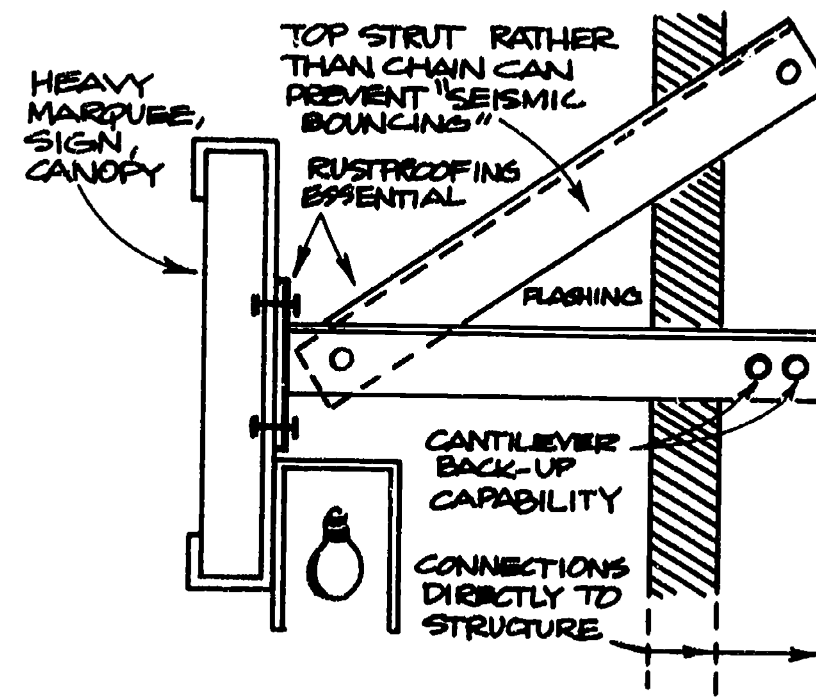
LIFE SAFETY HAZARD — $ % OF REPLACEMENT VALUE DAMAGED — POST-EARTHQUAKE OUTAGE

EXTERIOR ORNAMENTATION AND APPENDAGES

DAMAGE EXAMPLE

earthquake: 1979 Imperial Valley, California
credit: Robert Reitherman/BSD, Inc.

PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: negligible cost above usual wind resistance requirements

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▥
LIGHT	slight chance of dislodgment	mod	0–10%	low
MODERATE	strong chance of dislodgment of fragments	high	10–30%	mod
SEVERE	high chance that many fragments or entire objects will fall	high	30–100%	high

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▥
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	slight chance of dislodgment of occasional fragment	low	0–10%	low

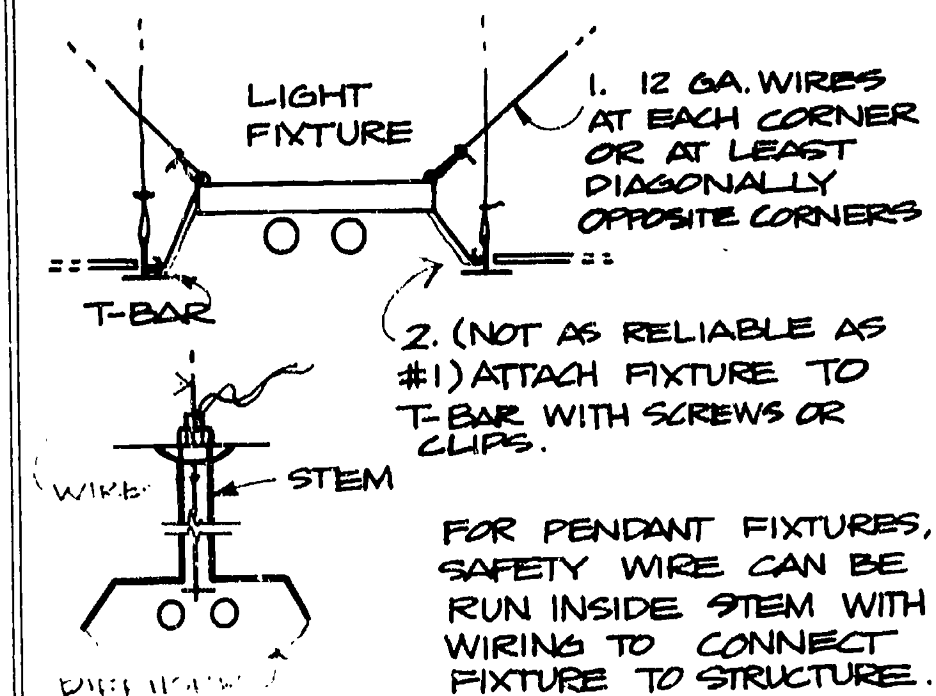
✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED ▥ POST–EARTHQUAKE OUTAGE

LIGHT FIXTURES

DAMAGE EXAMPLE

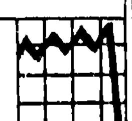
earthquake: 1971 San Fernando
credit: John F. Meehan

PROTECTIVE COUNTERMEASURE

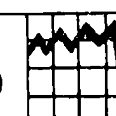


APPROXIMATE COST: $30

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	
LIGHT	occasional falling of fixture diffusers	low	0–5%	low
MODERATE	falling of some fixtures	mod	5–20%	mod
SEVERE	falling of many fixtures	high	20–80%	mod

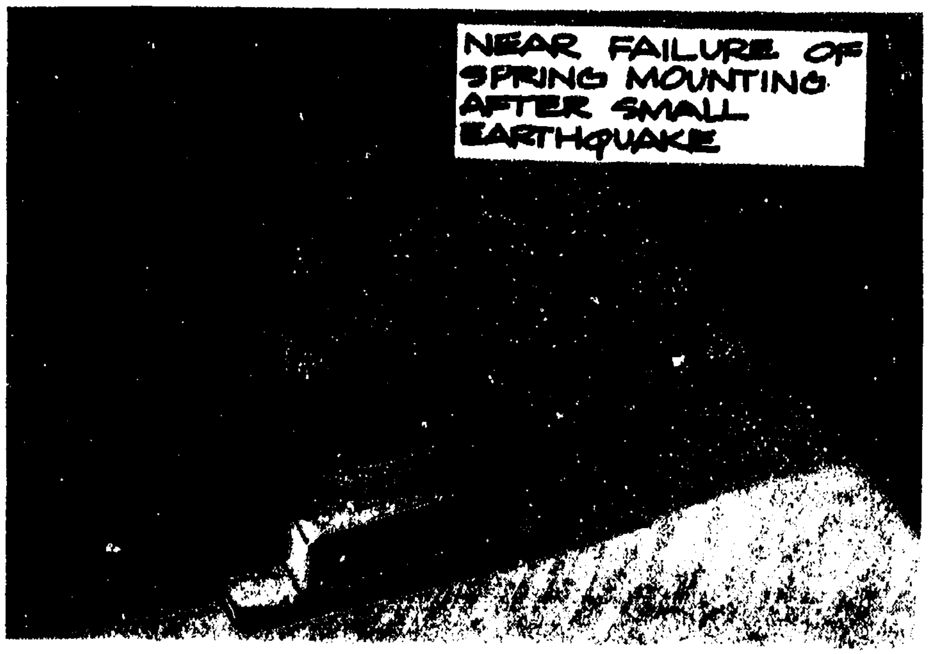
UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	slight chance of occasional falling of fixture diffusers	low	0–10%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED  POST–EARTHQUAKE OUTAGE

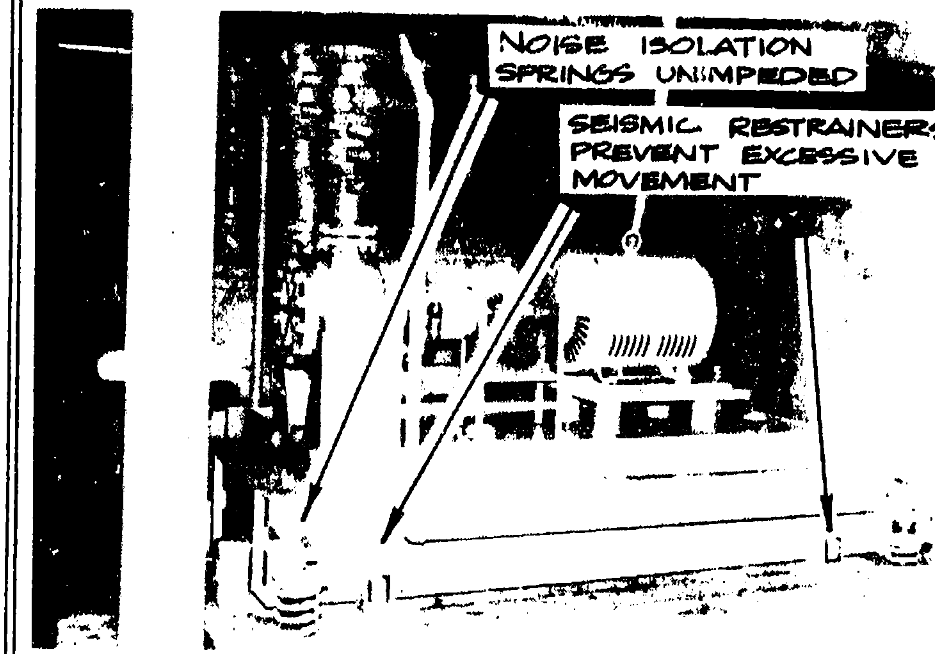
HEATING-VENTILATING-AIR CONDITIONING EQUIPMENT

DAMAGE EXAMPLE



earthquake: 1980 Livermore, California
credit: William T. Holmes

PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: $100 per piece of small equipment; $200 per large piece of equipment

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	LIFE SAFETY HAZARD	$	POST-EARTHQUAKE OUTAGE
LIGHT	no damage	low	0-5%	low
MODERATE	shifting of equipment; connections may be broken	low	5-20%	mod
SEVERE	falling, lurching of equipment off supports	mod	20-50%	mod

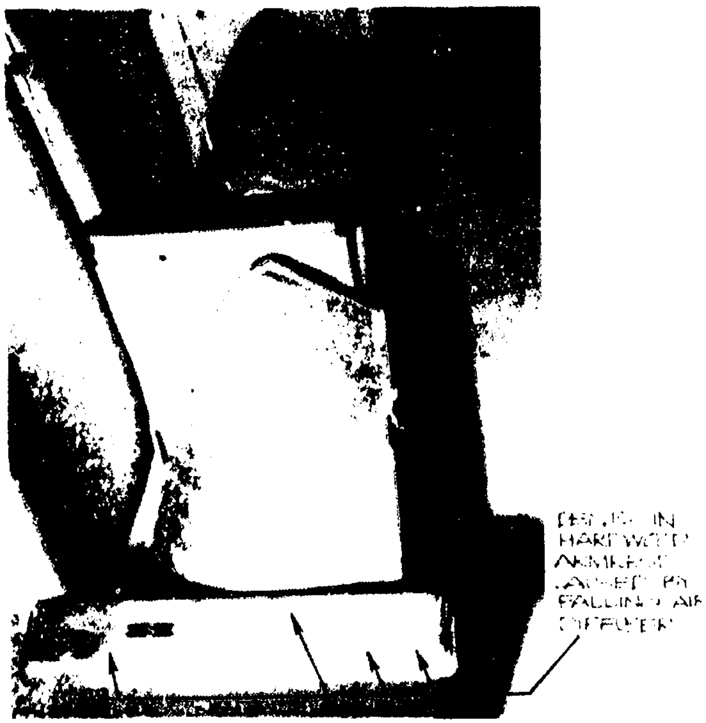
UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	LIFE SAFETY HAZARD	$	POST-EARTHQUAKE OUTAGE
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	any damage confined to piping connections	low	0-10%	low

LIFE SAFETY HAZARD — $ % OF REPLACEMENT VALUE DAMAGED — POST-EARTHQUAKE OUTAGE

HEATING-VENTILATING-AIR CONDITIONING DISTRIBUTION

DAMAGE EXAMPLE	PROTECTIVE COUNTERMEASURE



earthquake: 1971 San Fernando
credits: a) J. Ayres b) William T. Holmes

DIFFUSER SHOULD BE POSITIVELY ATTACHED (UNLIKE THIS ONE) TO DUCT OR CEILING, WHICH MUST IN TURN BE BRACED, OR TO STRUCTURE ABOVE

APPROXIMATE COST: $10–20 per diffuser

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	OUTAGE
LIGHT	occasional falling of diffuser	low	0–5%	low
MODERATE	swinging of ducts; occasional falling of diffusers, grills	mod	5–20%	mod
SEVERE	falling of ducts, mixing boxes, as well as diffusers	mod	20–80%	high

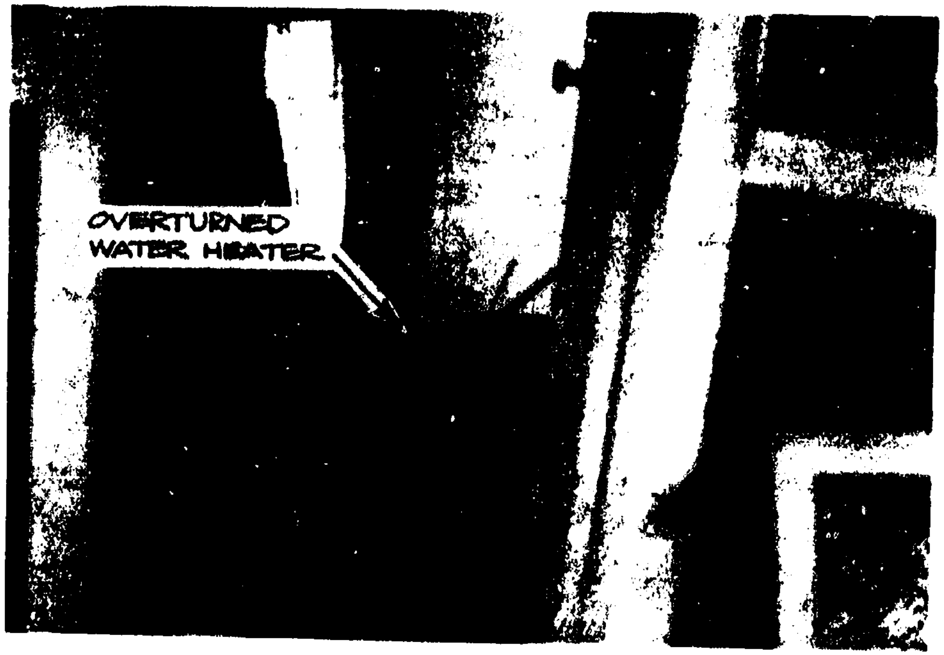
UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	OUTAGE
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	chance of localized damage but no falling of ducts	low	0–10%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED ▦ POST-EARTHQUAKE OUTAGE

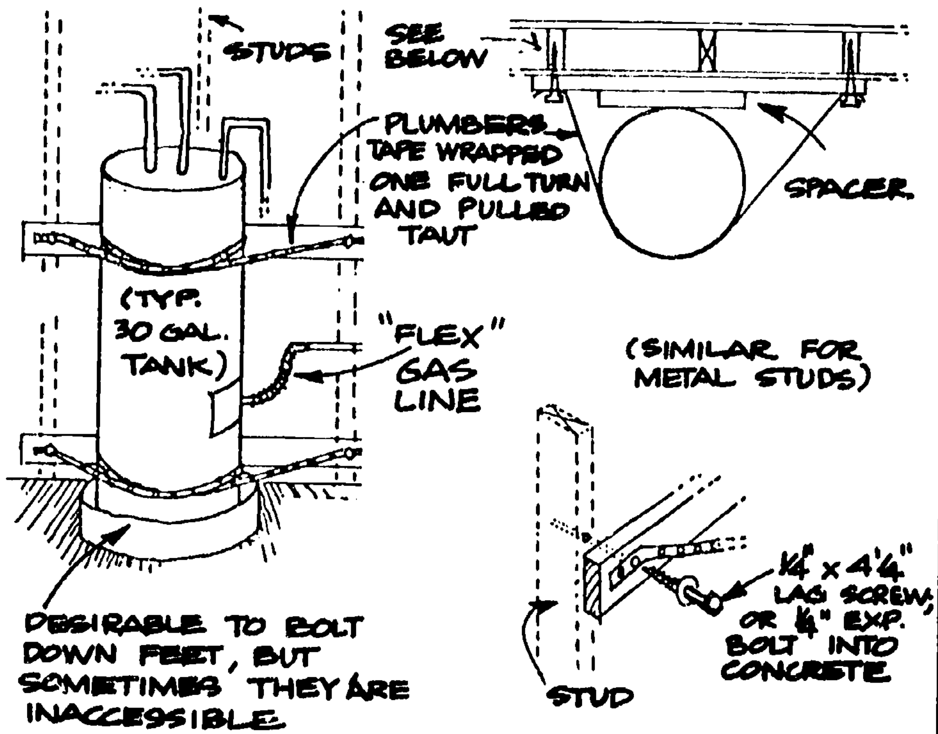
WATER HEATERS

DAMAGE EXAMPLE



earthquake: 1971 San Fernando
credit: Scientific Service, Inc.

PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: $50–100

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▦
LIGHT	chance of leakage of piping	mod	0–10%	mod
MODERATE	rocking but no tipover of tank; piping damage	high (fire)	10–30%	high
SEVERE	overturning of tank; note that fire caused by heater damage would cause futher losses	high (fire)	30–100%	high

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	▦
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	damage to rest of water or gas–electrical system more likely than heater damage	low	0–10%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED ▦ POST–EARTHQUAKE OUTAGE

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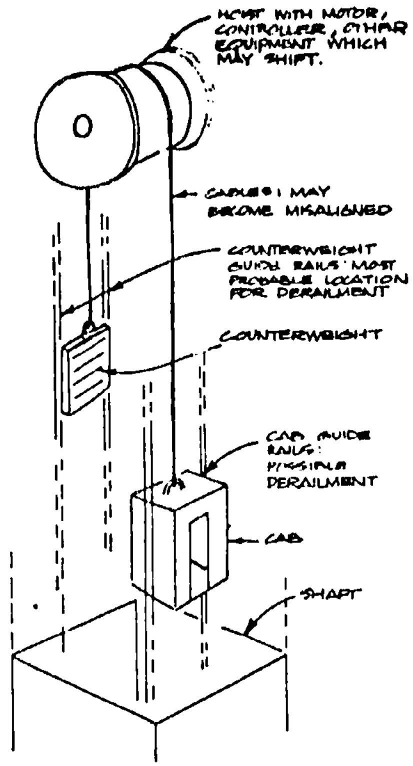
ELEVATORS

DAMAGE EXAMPLE



SCHEMATIC DIAGRAM OF CABLE (OR TRACTION) ELEVATOR.

(RETROFITTED ELEVATORS IN CALIFORNIA SHOULD PERFORM LIKE UPGRADED CASE AT RIGHT).

PROTECTIVE COUNTERMEASURE

— RETROACTIVE CALIFORNIA ADMINISTRATIVE CODE RULES HAVE NOW RESULTED IN SEISMIC SWITCH RETROFITS AND UPGRADED BRACING. (OCT. 1982 DEADLINE)

— ELEVATORS WILL SHUT DOWN, OR CAN BE OPERATED AT SLOW SPEED WITH KEY, AFTER EARTHQUAKE TRIGGERS SWITCH.

— HYDRAULIC ELEVATORS MORE LIKELY TO REMAIN FUNCTIONAL; USUALLY FOUND ONLY IN LOW-RISE BUILDINGS.

APPROXIMATE COST: $2,500 per elevator, compared to early 70's designs

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	Life safety hazard	% of replacement value damaged	Post-earthquake outage
LIGHT	slight chance of brief shutdown	low	0-5%	low
MODERATE	most elevators temporarily inoperative	mod	5-20%	mod
SEVERE	counterweight derailment, other severe damage; cab may be damaged; elevator room damage	high	20-80%	high

UPGRADED VULNERABILITY

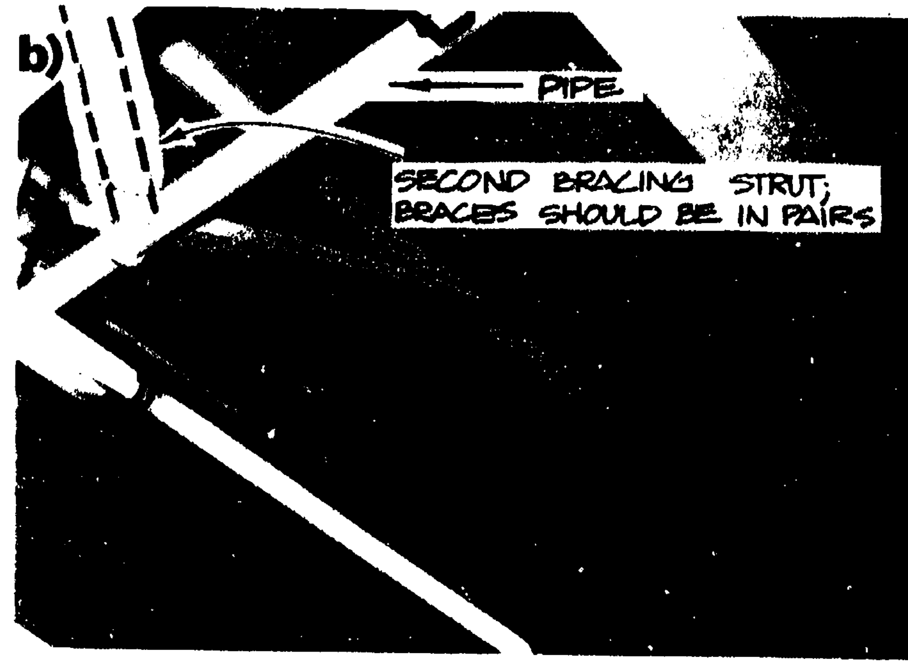
SHAKING INTENSITY	EFFECTS	Life safety hazard	% of replacement value damaged	Post-earthquake outage
LIGHT	no damage	low	0%	low
MODERATE	elevators with seismic switches may briefly shut down	low	0-5%	low
SEVERE	shutdown of elevators, but soon back in use; chance of damage to minority of elevators; backup power required	low	5-10%	mod

LIFE SAFETY HAZARD — $ % OF REPLACEMENT VALUE DAMAGED — POST-EARTHQUAKE OUTAGE

PIPING

DAMAGE EXAMPLE	PROTECTIVE COUNTERMEASURE

SMALL DIAMETER PIPES GENERALLY PERFORM WELL; DAMAGE-PRONE LOCATIONS ARE WHERE PIPES INTERSECT AT RIGHT ANGLES, ESPECIALLY WITH THREADED JOINTS.



earthquake: 1971 San Fernando
credit: a) John F. Meehan b) William T. Holmes

APPROXIMATE COST: $50 per bracing pair

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	
LIGHT	occasional leak of weak joint	low	0–5%	low
MODERATE	occasional breakage at weak joint	mod	5–20%	mod
SEVERE	falling of piping; note that secondary damage to leaks will also occur	high	20–100%	high

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	slight chance of leaks at weaker joints	low	0–10%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED POST-EARTHQUAKE OUTAGE

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STAIRWAYS

DAMAGE EXAMPLE

earthquake: 1971 San Fernando
credit: Lockheed

PROTECTIVE COUNTERMEASURE

- TO PREVENT DAMAGE TO STAIRS, THEY SHOULD EITHER BE:
  - ALLOWED TO SLIDE AT LANDINGS WITH "GANG PLANK" DETAILS; DESIRABLE FOR FLEXIBLE FRAME BUILDINGS
  - TREATED STRUCTURALLY AS DIAGONAL STRUTS; INTEGRAL WITH FLOORS/WALLS; COMMON FOR SHEAR WALLED STAIRWAY CORES.
- TO PREVENT DEBRIS FROM FALLING ON STAIRS:
  - NO BRITTLE ENCLOSURE WALLS (SUCH AS LIGHTLY REINFORCED BLOCK)
  - STRONG ATTACHMENTS FOR PIPES, LIGHTS, ETC. IN STAIRWELL

APPROXIMATE COST: varies considerably

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	LIFE SAFETY HAZARD	$	OUTAGE
LIGHT	no damage to slight-cracking	low	0–5%	low
MODERATE	major cracking, some debris on stairs if enclosure walls are brittle	low	5–20%	low
SEVERE	falling of debris from brittle enclosure walls; with severe building damage, collapse of stairway	mod	20–100%	high

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	LIFE SAFETY HAZARD	$	OUTAGE
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0–5%	low
SEVERE	slight cracking but still safe and usable	low	5–10%	low

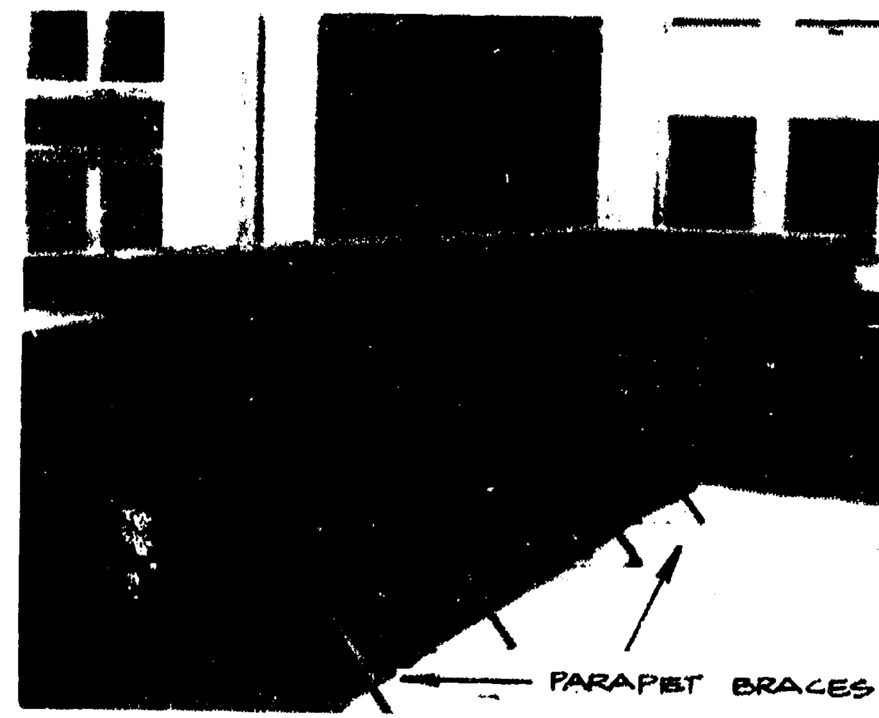
✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED POST–EARTHQUAKE OUTAGE

PARAPETS

DAMAGE EXAMPLE

earthquake: 1979 Coyote Lake, California
credit: a) Robert Reitherman; b) William T. Holmes

PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: $5–10 per lineal foot

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	LIFE SAFETY HAZARD	$	POST-EARTHQUAKE OUTAGE
LIGHT	some small pieces may dislodge	low	0–5%	low
MODERATE	some old deteriorated parapets fall	high	5–50%	mod
SEVERE	nearly all nonreinforced or deteriorated parapets fall	high	50–100%	high

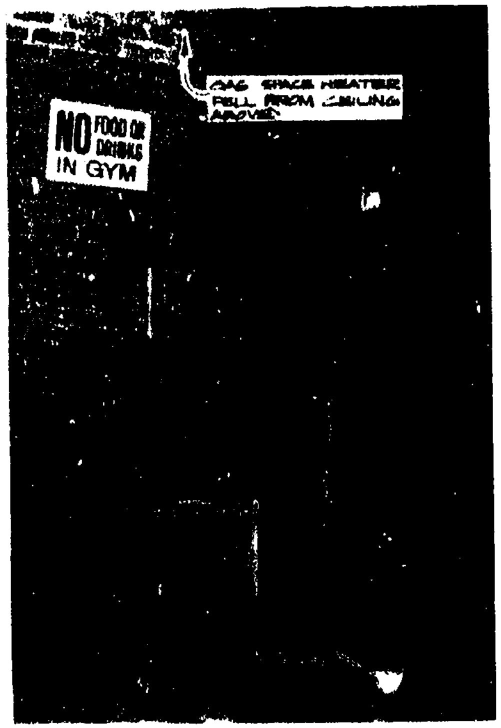
UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	LIFE SAFETY HAZARD	$	POST-EARTHQUAKE OUTAGE
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	some cracking or dislodgement of small pieces	low	0–10%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED   POST–EARTHQUAKE OUTAGE

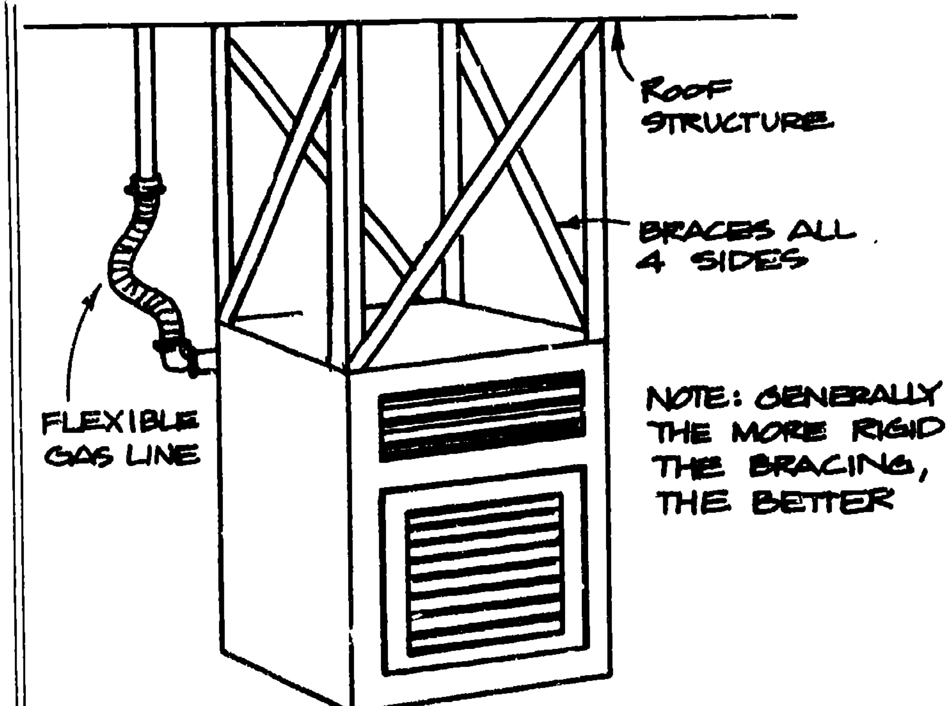
HANGING SPACE HEATERS

DAMAGE EXAMPLE



earthquake: 1971 San Fernando
credit: C. Wilton, Scientific Service, Inc.

PROTECTIVE COUNTERMEASURE



APPROXIMATE COST: $100 per heater

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	Post-earthquake outage
LIGHT	slight chance of enough swaying to cause gas leaking	mod	0–20%	low
MODERATE	likely that swaying will cause damage or gas leak; also fire damage	high	20–50%	low
SEVERE	severe damage; falling unless connections of hangers are unusually strong; also fire damage	high	50–100%	mod

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	Post-earthquake outage
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	chance of enough swaying to cause slight damage, but no leaks/fires	low	0–5%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED POST–EARTHQUAKE OUTAGE

4. Developing Earthquake Protection Programs

The preceding sections of this booklet have provided you with information. Now, how do you apply this information?

Estimating Vulnerabilities

The first step in using the information in this booklet is to estimate the vulnerabilities of the nonstructural components found in your facility. In complex cases, consultant expertise may be advisable, and this is discussed below. If you have no major potential problems, a major effort to deal with nonstructural damage may not be warranted. In many cases, a non-engineer can at least make a preliminary assessment of the approximate degree of risk by use of the information presented and by keeping in mind three basic questions as each nonstructural item is considered as found in your facility:

Would anyone get hurt by this item in an earthquake?

Would a large property loss result?

Would interruptions and outages be a serious problem?

This will produce a tentative list of items to consider in greater detail, and in most cases a large number of items will not present a significant enough problem on one of these grounds to justify further attention, though at this initial stage, it is better to be conservative and overestimate vulnerabilities than to be optimistic. The list can always be shortened later. Figure 17 is provided here to aid in the process of tabulating nonstructural items and estimating their vulnerability based on the commentary provided earlier. Figure 18 illustrates how this blank form might be filled in (though extra photocopied sheets would often be necessary to cover the array of nonstructual items found in most buildings). After listing the items in whatever order they appear in the process of surveying the facility, attempt to rank the priority for more attention of each item from number one to the least important in the column provided.

Estimating Costs

For each of these items, the cost estimating factors provided in the charts of Chapter 3 can be used to pro-

Figure 17

Summary Chart

Facility ____________________ Assumed Intensity ____________________

PRIORITY	NONSTRUCTURAL ITEM	LOCATION	QUANTITY	VULNERABILITY			ESTIMATED RETROFIT COST, EACH ITEM	ESTIMATED RETROFIT COST, SUBTOTAL	NOTES
				✚	$	▦			
							TOTAL		

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED ▦ POST-EARTHQUAKE OUTAGE

Figure 18

Illustration of Use of Blank Form of Figure 17

Facility: XYZ OFFICE   Assumed Intensity: Severe

PRIORITY	NONSTRUCTURAL ITEM	LOCATION	QUANTITY	VULNERABILITY ✚	VULNERABILITY $	VULNERABILITY Outage	ESTIMATED RETROFIT COST, EACH ITEM	ESTIMATED RETROFIT COST, SUBTOTAL	NOTES
4	air conditioner	roof	1	mod	25-75%	mod	$100	$100	sits on springs; no seismic restraints;
5	suspended ceiling	throughout	5000 sq. ft.	mod	100 %	mod	$.20/sq. ft.	$1,000	no diagonal wires
1	water heater	utility room	1	high	100 %	high	$50	$50	gas fired; no flexible pipe; no anchorage
3	tall shelving	employee storage	40 lin. ft.	high	100	low*	$5/lin. ft.	$200	* low because contents not essential; unanchored; 8 ft. high
6	freestanding partitions	secretarial stations	20 @ 6 ft.	low	0-5%	low	0	0	stable layout (returns)
2	fluorescent lights	offices and lobby	50	high	25-100 %	mod	$30	$1,500	fixtures just rest loosely on ceiling grid
							TOTAL	$2,850	

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED   POST-EARTHQUAKE OUTAGE duce subtotals for all of the items in each category. When added together, these subtotals will produce an estimated total seismic retrofit cost for the entire facility. For new construction rather than existing buildings, if nonstructural protection measures are taken into account early in design, the costs will be much less. If a number of repetitive protective measures are to be installed in a large facility, the unit cost will also be lowered. For both these cases, at least a 10% lower figure can be assumed.

Included within a consideration of costs should be any disruptions that installation of retrofit devices might necessitate, or any inconveniences associated with them in daily use. For example, some of the retrofit measures described could only be implemented when the building was not in normal use, and the installation of straps or other removable restrainers implies that the user will re-attach the strap each time the anchored item is moved.

By photocopying the blank form in Figure 17 and developing different lists, the prioritizing process can be done more easily by doing it in a few steps, rather than in one initial tabulation. One list can describe a more complete retrofit package with more costs added in, while another can add up a more minimally protective but also less expensive package that deals with only the most prominent problems. It is also possible to list the items first for one intensity of shaking, such as severe, and then for another intensity (moderate). In this way you will see the difference between these two levels of protection. General advice on the subject of where to draw the line between completeness and quality on the one hand and cost on the other is difficult to provide, except to note that it is better to focus on the most significant problems and tend to them efficiently than to develop all-inclusive lists that are too extensive to implement. A two phase approach may be desirable: Draw up and implement a short list of the most critical upgrading projects, and then after evaluation of the success of that first phase program, develop a second phase program to deal with other items farther down on the list. Only a very few people have ever had occasion to have any experience with implementing nonstructural earthquake protection measures, and hence starting small may be a wise approach. Seismic retrofitting is easier than it might at first appear, and experience with the administrative and technical aspects of the process are quickly gained, so the important thing is to make a start and do the first effort well.

As an aid in assigning priorities, you may refer back to Figures 7, 11, and 14 in Chapter 2 which list typical nonstructural items found in office, retail, and government buildings respectively. These suggested priorities cannot take into account whether items in specific cases are already seismically protected. There are valid reasons for why some individuals might rank these problems differently, depending primarily upon how much risk is considered acceptable and how much money is available to deal with the problem.

Implementation Strategies

How should protective techniques be implemented? The answer depends upon the nature of the physical conditions in the facility and the characteristics of the organization. The following suggestions can be considered by the reader in the context of his or her own situation.

Self-help vs. Use of Consultants - Self-help implementation of a program can be adequate where the probable seriousness of any problems is small or the in-house familiarity with engineering or construction is greater than average. For larger facilities, engineering or architectural-engineering consultants may be quite cost-effectively employed to survey for vulnerabilities and design retrofits. The proverb has it that "an engineer is someone who can do for one dollar what any damn fool can do for two." In some cases, after an initial survey is conducted and a report prepared by an expert, the remainder of the implementation could be handled in-house without further assistance. One of the larger nonstructural earthquake hazard evaluation and retrofit programs is that of the Veterans Administration for its hospitals, and the typical procedure followed by the VA has been to hire consultant experts to first assess the site's risk of experiencing significant shaking, then to review the facility and list specific items which are vulnerable to future earthquakes, grouped by priority and with estimated costs. The VA's own maintenance staffs at each hospital then are given many of the implementation tasks after the consultants established the outline of a program. As mentioned in the introduction, there are limits to the self-help diagnosis and prescription approach, and especially if larger buildings, or more serious safety hazards, property risks, or critical functional requirements, are involved, the use of a consultant may be advisable.

Earthquake Engineer - This is a commonly used term, but the State does not have any such license category, and "earthquake engineers" are not listed in the Yellow Pages. A structural engineer (see below) experienced in earthquake analysis is the basic definition of "earthquake engineer".

Structural Engineer - A structural engineer is a civil engineer (see below) who has gone on to obtain an additional license from the State based on work experience and examinations specifically on topics relating to structural engineering. Structural engineers are more likely to be familiar with building construction than many civil engineers who specialize in other areas. Some structural engineers have had extensive experience in designing nonstructural anchorages and protective measures, often involving hospitals because of their stricter building code requirements. Structural engineers are listed in the Yellow Pages under "Engineers, structural."

Civil Engineer - A civil engineer is licensed by the State. Some civil engineers specialize in fields such as airport and harbor design, utility systems, or soils engineering that do not involve the structural design and analysis of buildings.

Mechanical Engineer - A mechanical engineer has obtained a State license based on education, experience, and examinations. Some mechanical engineers practice aspects of their discipline completely unrelated to buildings (such as the design of power plants, automotive engines, or machinery). Mechanical engineers who specialize in the design of HVAC (heating-ventilating-air conditioning) systems, or "mechanical" systems, for buildings, are often familiar with these types of nonstructural items, but they typically rely on structural engineering consultants for the design of earthquake bracing of mechanical equipment.

Architect - An architect is also licensed by the State based on education, work experience, and examinations. Since architects must be knowledgeable about many aspects of building design and construction, generally only a small part of their education, work experience, and examinations, has been devoted to structural engineering, and even architects licensed in California are not generally capable of making seismic computations and structural detailing decisions as can a structural engineer. In general, architects rely on in-house or consultant structural engineers, and on new construction, the engineer works for the architect rather than directly for the owner. Architects are generally responsible, rather than the engineer, for the design of windows, partitions, ceilings, and many other nonstructural items. It is important, therefore, for the architect to be made aware of the concerns of the client on the subject of protection from nonstructural earthquake damage.

Interior Designer - An interior designer or space planner need not have any particular background in engineering, though in some cases this designer will be most intimately involved with the specification of file cabinets, furniture, finish materials, etc. Designs by interior designers can be reviewed by a structural engineer to assure appropriate detailing to deal with earthquake hazards.

Speciality Contractors - Contractors in various specialties, as well as in the category of general contractor, are licensed by the State. Contractors can implement retrofit schemes designed by others, or in some cases can help devise the retrofit technique if no formal engineering is required. Contractors who are experienced in installing new suspended ceilings up to earthquake resistant standards, for example, may be skilled at the seismic retrofitting of existing ceilings.

Integration with Maintenance Programs - One of the easier means of gradually implementing earthquake protection into an existing building is to train maintenance personnel to identify and correct nonstructural hazards that they may discover as they survey the building for other purposes, or to correct the problems identified by an engineer as in the case of VA hospitals. A disadvantage of this approach is that the protection is only gradually increased, and in some cases the economy of doing several related upgrading projects at the same time is not exploited. Note below under the heading of sustaining protection that a maintenance program can also be used for upkeep of protective measures.

Remodeling - If there are other reasons for remodeling, there may be an opportunity for increasing the protection of several nonstructural components at the same time, especially ceilings, partitions, windows, air conditioning ducts, or other built-in features. In many cases, remodeling efforts have lessened rather than increased earthquake protection by the accidental modification of components that originally received some seismic-related attention from a structural engineer or architect. If an architect, interior designer, or contractor is handling the remodeling, the possibility of incorporating additional earthquake protection into the space should be discussed, and a structural engineer's expertise should be employed where indicated.

Incremental Upgrading - In some cases, it may be possible to deal with different areas within a building at different times, or to select one or more types of nonstructural components throughout a building and upgrade them at the same time. Some projects can be completed in a weekend, enabling equipment or other items to be retrofitted without interrupting the normal work flow, for example. Companies with annual shutdowns may find upgrading the highest priority items as each shutdown occurs the easiest course. Retrofit work that interrupts the use of a space, such as bringing in ladders or scaffolding to work on the ceiling or ceiling-located items, could be restricted to limited areas in a facility at a given moment, minimizing the overall disruption.

New Construction - In this case there is the possibility of anchoring, bracing, or restraining all items at the same time according to a unified design. As noted earlier, nonstructural upgrading work in new construction is more efficient and less costly than retrofitting existing buildings. This all-at-once implementation process can also be used in existing facilities either when the extent of the work required is not too great, or when the work is extensive but the resulting disruption implied is tolerable. When a building is temporarily vacant, it is a favorable time for this approach. If the organization is large, the development and adoption of nonstructural guidelines to be used by designers or contractors could be considered; this is discussed in Chapter 6. For small companies or organizations, at least a letter or conversation could be devoted to bringing up the problem of designing earthquake resistance into nonstructural items. Providing the architect or other designer with a copy of this booklet would be advisable.

Sustaining Protection - Some nonstructural protection devices, such as anchorage hardware for exterior objects, may deteriorate with time if not protected from rust. Interior fastenings and restraints may be removed over time as people move equipment or other items and fail to re-install the protection devices. Figure 19 illustrates a common problem in maintaining the "human" rather than "hardware" aspect of nonstructural protection. As noted above, remodeling projects can result in elimination of protective features if there are no seismic guidelines. Training is required to insure that gas cylinders, storage rack contents, office equipment chemicals, etc. are properly stored.

Maintenance personnel may be the likely people to periodically survey the building to see if earthquake protection measures are still effectively protecting mechanical equipment, such as emergency generators, water heaters, etc. Supervisors can be made responsible for an annual review of their work spaces. If there is a separate facilities or physical plant office in an organization, that may be a logical place for the responsibility for sustaining protection to reside. Organizations with safety departments have successfully assigned the role of overseeing nonstructural earthquake protection to this functional area.

In the case of the University of California, Santa Barbara, the implementation and maintenance of a campus-wide program of preventing nonstructural earthquake hazards was initiated by a one-page policy memo from the chancellor. Each department head was made responsible for implementation of the policy, and the campus Office of Environmental Health and Safety was given the job of advising departments on implementation, making surveys, and evaluating the overall program's effectiveness, (Refs. 8 and 9).

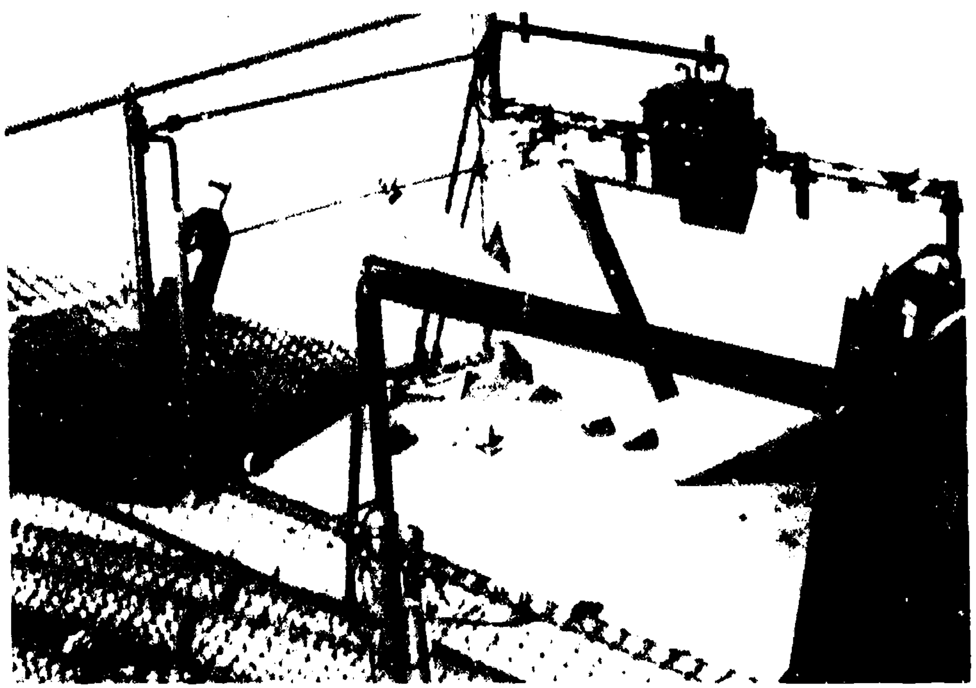
Evaluation

How good is your nonstructural earthquake protection program? Is it worth the cost? How do you evaluate its strong points or deficiencies?

There are two basic criteria to employ in accomplishing this task. First, how well has the program met its stated objectives? Have the costs been within budget? Have the tasks been completed on schedule? Is the scope of the effort as broad as was intended, or have nonstructural items been neglected which were targeted for retrofitting, or have employee training units or exercises of additional response plan features not yet been implemented? And finally, how good is the quality of the measures implemented? Have the retrofit measures been correctly installed? Is the training taken seriously?

The second basic evaluation technique is to ask: If the earthquake happened today, how much better off

a. Example of a "human" rather than "hardware" problem in maintaining protection from nonstructural damage: the chains provided are not being used.
Photo credit: William Holmes



b. Example of damage to unrestrained gas cylinders in the 1971 San Fernando earthquake. A fire occurred nearby at this facility when an oxygen tank leaked.

Photo credit: C. Wilton, Scientific Service, Inc.

Figure 19

Sustaining Nonstructural Protection

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would we be than if we had never developed a nonstructural protection program? This can be done in a rough cost-benefit format by estimating the total cost of the program, including estimates of staff time not charged to that particular project, which will be the "Cost" portion of the ratio. The benefit is essentially the difference between the expected loss without the program and the expected loss with the program.

The information in Chapter 3 can be used to estimate these costs of damage. In many cases, the value of not experiencing outages, or of preventing injuries, will be very significant, and property loss savings cannot be the sole measure of the benefit. Cost-benefit computations should only be used as a guide, rather than as automatic decisionmaking devices, since the earthquake costs and especially the benefits can only be very approximately estimated.

5. Emergency Planning Guidance

What types of nonstructural damage should be considered and dealt with by an earthquake response plan? How should training and exercises be conducted to properly take into account the prospect of nonstructural damage?

Implications of Nonstructural Damage for Emergency Planning - The first step is to develop a valid picture of the probable post-earthquake state of the facility. The nonstructural survey and vulnerability analysis will indicate what types of items are present and will at least approximately assess their earthquake resistance. The better this survey and analysis, the more likely the envisaged post-earthquake conditions will actually materialize, while less expert assessments will be more likely to either over- or under-estimate damage. Even with the most thorough of analyses, however, there is still great uncertainty in the process of estimating earthquake performance.

One approach to this uncertainty is to assume the worst. This conservative approach is not warranted and is prohibitively expensive for purposes of allocating construction money to retrofit items, but it may be inexpensive in the initial stage of the emergency response planning process to at least briefly consider the impact of severe damage to each nonstructural item on the list. Ask yourself this simple question: What would be the emergency planning implications if each particular nonstructural item were to be severely damaged?

As a first step, consider the possibility that an emergency power generator, for example, will be damaged or its supporting services rendered inoperative, and consider the consequences. This will provide the worst-case scenario.

Your particular generator may be anchored with adequate bolts into the concrete slab, it may have its own fuel supply rather than rely on natural gas, the batteries may be restrained, and the cooling water system, if any, may be earthquake protected. You test your generator monthly. You are confident that your generator will work after an earthquake. However, out of 100 very well protected generators such as described above, at least a few would probably fail to run after a large earthquake. The probable outcome is that the generator will work properly, but there is still an outside chance that it won't. If there are inexpensive backup planning measures to include in written plans, or in training or exercises, then this may be a form of inexpensive insurance. Such inexpensive measures might include: occasionally including in an earthquake scenario the complete absence of electricity (by switching off all electricity except where it would be dangerous to occupants or deleterious to equipment); testing battery-powered exit lights; buying a few flashlights; maintaining a list of local supplies of rental generators; and exploring whether recreational vehicle generators could supply power to run some essential functions, and if so, including the idea as a backup tactic in the earthquake plan so that employees could be quickly queried to see if some RV's might be available for use by the company or organization.

After at least thinking about the worst-case implications with regard to each nonstructural item, it will then be necessary to move on to the probable case scenario. Because emergency planning resources are limited, extensive effort cannot be devoted to every conceivable problem. Based on the approximate estimates of damage provided in chapter 3 and summarized using Figure 17 of Chapter 4, a description of the damage for each item is available. If items are actually in the process of being retrofitted when emergency planning is underway, the upgraded performance could be used as a basis for planning rather than the greater damage that is associated with the as-is case.

For almost all types of nonstructural damage, the often-stated advice to take cover beneath a desk or table is valid. While the photos of earthquake damage presented earlier may look frightening, a detailed look will show that if an occupant had been in the vicinity of the damage but kneeling under a desk or table, it would have been very difficult for injury to have resulted. Standing in a doorway would have provided some protection, but less than taking refuge under a desk or table. This advice, while very simple, requires some training and exercises if the technique is to work. Some people may have an immediate impulse to try to run outdoors if the shaking is severe or lasts for more than a few seconds. Many adults will feel embarrassed about crawling under a table. The frequent earthquake drilling of students that occurs in California public schools appears to be very successful in getting students to quickly take cover and follow instructions during earthquakes, and similar drills, if only annual, are required if adult office workers, salespersons, or government employees are to also protect themselves if the need arises.

In settings where there are no desks or tables, occupants should get down beside the next best thing: In an auditorium or public assembly setting, kneeling down between the seats is the best advice.

Earthquake Plans

The following points relating to nonstructural damage should be covered in an earthquake plan.

Pre-earthquake Tasks - The document can describe the identification and retrofitting of nonstructural items, and procedures for routinely checking to see that protective measures are still effective. If employees are expected to be briefly instructed in what to do in case of earthquake, and to have a brief drill, then that should be written into the plan also.

Earthquake Emergency Response Tasks - During and immediately after the earthquake, what tasks should be accomplished? The tasks can be made contingent upon the severity of the earthquake and the amount of damage that is immediately seen to have occurred. If the structure of the building is obviously damaged -- there are sizable cracks in concrete walls, floors or columns, or the building stands out of plumb, or any portion of it has pulled apart or collapsed -- then evacuation of the building rather than a thorough survey of nonstructural damage will obviously be in order. If there is no apparent structural damage, a survey of the mechanical equipment, elevators, etc., could be listed as the appropriate response.

Responsibilities - For each task, someone must have responsibility. If no responsibility is stated in a plan, it is likely that no one will carry out the task. Because the earthquake may happen at any time (and will have a two-thirds chance of happening outside normal work hours), back-up positions for responsibilities should be listed. It is preferable to list positions rather than individuals' names to minimize the obsolescence of the plan, but in any event, someone must have responsibility for the plan itself and keeping it current. Figure 20 provides a blank form for use in collecting information which will often be found necessary in formulating an earthquake plan.

Training

How should you establish an earthquake training program? Ironically, the best advice may be to avoid establishing an earthquake training program; instead, integrate earthquake training tasks into other ongoing training programs. The infrequency of earthquakes can cause the best of training programs to slowly lose their effectiveness or completely die out if the only impetus behind the training is the earthquake threat. An earthquake training program that requires its own separate funding will probably have a relatively low priority in the overall ranking of training concerns, whereas ways of slightly expanding existing training programs may be found to deal with the problems unique to earthquakes at small cost.

Fire safety is typically the most common of hazards around which hazard training is based. In the process of instructing employees about extinguishers, alarms, notification procedures, safe storage methods, exiting, and other fire-related topics, it may be possible to build in an earthquake safety training unit at the same time. Security staffs should be trained in the process of responding to earthquakes at the same time they are familiarized with other emergency plans for theft, fire, or other hazards. Maintenance personnel must be trained in certain upkeep and operational aspects of the heating-cooling-ventilating-system, elevators, plumbing, lights, sprinkler system, and so on, and many of these items are precisely the components of a building that will require attention in an earthquake hazard reduction or response plan. Workplace safety training sessions are ideal forums for dealing with the earthquake subject.

To keep the earthquake training requirements as few as possible, consider the unique aspects of earthquake problems that are not already covered by preparations for other hazards. For example, the fact that the phones may not work is one of the key ways in which earthquake response differs from that for fire or other hazards. Individual emergency plans may contemplate a telephone outage, electrical outage, need to evacuate the building, traffic disruption, injury, pipe leakage, or window breakage, but it is unlikely that any other hazard's plan will deal with all of these events occurring simultaneously. At a minimum, having an earthquake backup plan for reporting injuries or fires in the event that the telephones are inoperable, is one essential fea-

1. Facility/Organization name:

2. Address:

3. Building Ownership: ____owned by occupant, ____leased by occupant

4. Type of organization: ____company, ____government agency, ____other:

5. Organizational structure: (overali organizational chart)

6. Functional responsibilities
   Who has responsibility for:
      authorization for earthquake program, budgetting:
      detailed administration of earthquake program:
      safety training courses:
      posters, brochures, memos, newsletters:
      workplace safety, OSHA compliance:
      fire brigades, emergency response teams
      first aid, health care:
      personnel: absenteeism, help with personal problems:
      insurance:
      risk management, risk control:
      facilities management: new construction and remodeling:
      facilities management: maintenance:
      facilities management: operation of mechanical/electrical systems:
      facilities management: A & E; post-EQ safety inspections:
      security:
      operational authority for evacuations, building closings:
      public relations, press statements:
      communications:
      food service:
      transportation: personnel; cargo:

Figure 20
Information Gathering Checklist:
Organizational Characteristics

7. Relationship to off-site portions of the organization:
Which communication/transportation/interaction links are most essential?

1.

2.

3.

8. Relationship to other organizations: Which links are essential?

1.

2.

3.

9. On-site functions: Which are most essential?

1.

2.

3.

Figure 20 (continued)
Information Gathering Checklist
Organizational Characteristics

ture to include. The nearest fire station should be located and indicated on a street map so that aid can be quickly summoned in person if medical or fire aid is required and the phones are out. (Even if ambulance service does not operate through the fire department, the radio equipment available at any fire station will allow for communication with other agencies).

In addition to adding earthquake training to other ongoing training programs, it may be reasonable to occasionally devote brief training sessions exclusively to the earthquake subject, on an annual basis. An annual training scheule can be easily coordinated with an annual exercise schedule, as discussed below.

Exercises

In compiling a list of nonstructural damage situations for inclusion in an earthquake scenario to be used for an exercise, estimates of damage derived from Chapter 3 and summarized on Figure 17 of Chapter 4 can be used.

The list of nonstructural damage events may grow lengthy, and it may include potential nonstructural damage events which could only be simulated in an exercise at great cost or with great disruption of normal functions. Full-scale evacuations of high-rise buildings without the use of elevators are rarely conducted, for example, and rather one or two floors are evacuated periodically. Turning the electricity off accurately simulates an earthquake-caused power outage and the attendant problems of visibility in windowless office areas, lack of air conditioning, and so on, but this may be too disruptive, or in some cases unsafe, to do throughout an entire building. In a large company or government office, one department, one wing or work area of the building, could be included in a more realistic simulation of effects, while the remainder of the facility is allowed to function normally or only participates in a brief take cover exercise.

Employees with specialized earthquake response tasks, such as the maintenance personnel who should check for water or gas leaks, or supervisors who would be responsible for checking on the well-being of employees in their areas, or a safety or security officer responsible for communications within the building or with outside emergency services, should have more frequent training and exercises. An annual schedule of a brief exercise, such as having people take cover beneath desks and reminding them not to use elevators after earthquakes, is probably adequate, for most employees, whereas more frequent brief drills for specialized task employees may be warranted.

Master Earthquake Planning Checklist

The checklist in Figure 21 is keyed to the chapters in this booklet.

1. Establish executive policy requiring a nonstructural evaluation; allocate funds for initial work. Responsibility: CEO, Board of Directors, Manager, Executive Committee. See especially Chapter 1.

2. Survey for nonstructural vulnerabilities. Responsibility: outside consultant or in-house engineering, maintenance, safety, or other department. See Chapters 3 and 4.

3. Analyze the conditions found and estimate future earthquake behavior. Responsibility: same as number 2. See Chapters 3 and 4.

4. Develop a list of nonstructural items to be retrofitted, with priorities and cost estimates. Responsibility: same as number 2; may include bids from contractors. See Chapter 4.

4.1 If a facilities development guidelines document is to be produced, coordinate criteria to be used on future new construction with standards for retrofitting. Responsibility: same as number 2. See Chapter 6.

5. Decide what items are to be retrofitted, how the work will be done, and by whom. Responsibility: same as for number 1, with input from number 2.

6. Implement the retrofitting. Responsibility: in-house staff or contractors, with administration of contracting or tasking by number 2 or in-house construction administration office. See Chapter 4.

7. Develop an earthquake plan, with pre-, during, and post-emergency earthquake tasks and responsibilities itemized. Responsibility: consultant or in-house safety or other department, with general policy and budgetting same as number 1 above. See Chapter 5.

8. Train personnel in accordance with the plan of step 7. Responsibility: training, safety, or other department. See Chapter 5.

9. Plan and implement exercises which will test the training of step 8 and the planning of step 7. Responsibility: same as for 7 or 8. See Chapter 5.

10. Evaluate the performance of the above program, preferably within one year after inception or according the deadlines set in an implementation schedule, and annually thereafter. Responsibility: same as for number 1 in smaller organizations, or same as for 7 above. See Chapter 4.

Figure 21
Master Earthquake Planning Checklist

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6. Facilities Development Guidelines

For a large organization, the development of formalized nonstructural construction guidelines may be appropriate to control the work of architects, engineers, interior designer/space planners, and contractors. As a general rule regarding new construction or renovations, if the drawings do not show specific attachments and bracings, and if the written specifications do not mention earthquake protective devices such as anchors, braces, etc., then the contractor who builds or installs the items cannot be assumed to think up special protective measures and spend time and materials to implement them. The limitations of the current building code in solving the nonstructural earthquake damage problem were discussed in Chapter 1.

Written guidelines to prevent or limit nonstructural damage might include the following.

Scope

To what purchases, remodelings, or new construction do the guidelines apply? (They cannot apply to all nonstructural items since this broad definition would mean that furnishings such as waste paper baskets, desks, pictures hung on the wall, etc., would be included). Items to exclude might be lightweight non-hazardous, unessential and inexpensive items that are not mounted overhead or above a certain height off the floor (42 inches to 5 feet are criteria in use). Adherence to the building code could be considered adequate for all but certain specified items, such as computers or other essential equipment, which are called out.

The guidelines might apply only to work done by outside designers and contractors, in-house facilities work and maintenance, or individual workplace standards. It is preferable to address these three separate audiences separately. The scope could include new construction only, or renovations, or both. Including both cases is recommended.

Responsibility

Who has the in-house responsibility for maintaining the guidelines and assuring their implementation? This should probably be the same office that oversees or coor-

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dinates architecture and engineering projects at present. What responsibilities does the designer or contractor have for notifying or certifying to the owner that provisions of the guidelines are being followed? (This responsibility should become part of the contract.)

General Intent

The importance of the nonstructural earthquake protection program should be stated, preferably by a cover letter or introductory statement from the chief executive, department head or governing board. If the guidelines are the only assured means of communicating about the earthquake topic to designers or contractors, introductory information could be added as well (such as examples of the types of damage that might occur if the guidelines were not followed). This booklet provides more background information on this topic than most designers or contractors have previously acquired, and portions or all of it could be made available to them to accomplish this purpose.

Performance Criteria

If the client wants a design professional (architect or engineer) to do more than merely conform to the building code's minimum requirements, it is desirable to explicitly state the higher level of performance desired. This can be done in a verbal way, such as "In the event that the maximum credible earthquake occurs, the following nonstructural items should remain undamaged and functional, assuming the structure remains serviceable. For all other nonstructural items, only life safety is important, and the anchorage provisions of the Uniform Building Code should be followed with regard to any item weighing more than ____ pounds, or located more than ____ above the floor and weighing more than ____ pounds." The specified weight might be one pound per square foot, and the height five feet.

Another way to state the basic performance criterion would be, "Within ____ hours/days after the worst earthquake that is expected to occur on average once a century, the following nonstructural items would be at least ____ percent functional." Other published criteria could be referenced. For very important projects, some of the requirements imposed on California hospitals in Title 24 of the California Administrative Code might be appropriate, but this would have to be done selectively rather than referencing an entire code with all of its non-applicable provisions.

The criteria should include an indication as to how much the client is willing to pay to obtain the higher level of protection. Estimates could be prepared for each job and approved by the client, or a general statement that "any cost up to ____ percent additional cost" (with the percentage specified in terms of total construction cost or estimated cost for that nonstructural item only), which the architect or engineer thinks reasonable, is allowable, with costs estimated to be in excess of this limit to be brought to the attention of the client for explicit approval during design.

Quality Assurance

What means of verifying and testing compliance with the guidelines will be required? For example, specific procedures for test loading (pulling) a percentage of installed anchor bolts could be specified, if retrofitting anchorages into concrete slabs or walls is to be a common part of future projects. For installaton of drill-in anchor bolts in hospitals in California, which are subject to stricter earthquake regulations than for most buildings, for example, the Office of the State Architect requires in-place proof testing of half of the bolts to twice their allowable or design-basis loads, and if any bolts pull out then the adjacent bolts must also be tested.

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Coordination with Non-seismic Specifications, Codes, and Guidelines

The need to provide earthquake protection without sacrificing fire, security, or other requirements should be stated. One common conflict arises in the acoustically desirable use of vibration isolators to allow equipment such as air conditioning units or generators to operate without transmitting the full force of their noisy vibrations into the building see Figure 22. The easiest earthquake solution is to bolt the equipment rigidly to the supporting structure, but this would compromise the spring-mount vibration isolation system. Restraining angles can be installed which will still solve the earthquake problem while also allowing the acoustic solution to operate unhindered.

Earthquake Provisions of Building Codes and Standards

Most design and construction contract language will require compliance with locally applicable codes. However, as discussed in the introduction of Chapter 1, the building code does not deal very extensively with the nonstructural earthquake problem. Mere conformance with the letter of the law, the Uniform Building Code, would not require earthquake anchorage or restraint for a computer, tall file cabinet, heavy mirror, or small containers of chemicals. In addition, a client might desire some items that are listed in the code to be provided with a higher level of protection than the code minimums. The fact that the guidelines may call for measures in excess of code should be pointed out. "Whichever requirements are more restrictive" is a phrase that could be used to indicate that the code must be met, and if the guidelines so require, the code should be exceeded. This is related to the subtopic of Performance Criteria above.

Early discussions with the architect, engineer, or interior designer/space planner will help to deal with this issue. In new construction, an issue that is almost never articulated by the client (simply because the client is not knowledgeable about earthquake engineering) is the stiffness vs. flexibility decision. In the choice of the structural system for the building and in its detailed design, the architect and engineer can often choose rather flexible frame systems, which are economical because they can be designed for lower earthquake forces by code than a comparably sized rigidly walled ("shear wall") system. This was discussed briefly in Chapter 1. The drift or sway limitations in the code are only minimums set essentially on the basis of structural safety. Buildings designed to have less drift or horizontal swaying, the shear walled building or the building with a frame that is stiffer than the code minimum, will experience less nonstructural damage, and if the cost is small it may be advantageous to exceed the code's minimal requirements. Related to the drift problem is the desirability of providing movement joints to allow for protection of windows and partitions during earthquakes. If the owner expects to receive extra attention in the design of these features it is necessary to discuss it with the architect and engineer.

The design force level is another question. By "force level" we mean the amount of inertial or shaking earthquake force to design an item to resist. The building code specifies different percentages of the weight of an object to be used as the horizontal earthquake force, as mentioned in Chapter 1. As also noted earlier, many items are not even covered by the code, and hence the conscious selection of inertial force levels will be required by the client or design professional. Requiring a 100% coefficient (if the object weighs 100 pounds, then its anchorage must be able to resist a horizontal force of 100 pounds) would be a generally conservative criterion for most items in most buildings in California, for example, although the cost of

Figure 22

Disregard for Seismic Protection

The warning label was intended to prevent transmission of machinery vibrations into the floor; however, in seismic areas, earthquake restraint must also be accomplished

Photo credit: William T. Holmes

this extra conservatism is often small since the labor will probably be the same and the difference in hardware costs are generally quite small.

Prescriptive Details

If there are efficient and safe specific methods of dealing with repetitive nonstructural problems, then these might be detailed with drawings and required where applicable. Chapter 3 provides a starting point for the development of such standard details, which should be reviewed by a knowledgeable design professional to insure their appropriateness for the cases at hand. The references listed in the Bibliography are other useful sources of information.

Fees

If the architect, engineer, or interior designer/space planner is called upon to perform a service not usually provided, the fee will logically be higher. For office and commercial buildings, standard practice would dictate that only a very small amount of the architect's or engineer's time would be spent on nonstructural protection to meet minimum code requirements. If the work is performed on a time and materials basis, rather than as a percentage of construction cost, the extra work spent on seismic problems is already accounted for. Designing details for a variety of types of nonstructural situations can be time consuming.

7. Appendix: Structural Damage

This booklet is focused on the nonstructural rather than structural aspects of earthquakes, but the following brief comments provide an introduction to important structural problems and solutions.

In California, most buildings will perform well in earthquakes. The first fact to grasp is that localized destruction is the threat California faces, rather than the near-complete leveling of towns, which has occurred in Morocco, Iran, Turkey, Chile, and other countries. After past California earthquakes, the typical scene in the most heavily shaken area is that one building on a block will collapse, while the others, although perhaps damaged to varying degrees, remain intact and standing. Scenes of San Francisco reduced to rubble in 1906 are post-fire photos, not post-earthquake photos. See Figure 23, an aerial photo taken just after the 1925 Santa Barbara earthquake. As was the case with the 1906 San Francisco earthquake (before the conflagration spread), 1933 Long Beach earthquake, and 1952 Bakersfield earthquake, such a panoramic photograph will portray the city as relatively intact. On close inspection, a few collapsed and a good many partially damaged buildings can be seen, and others are damaged internally, but not collapsed or visibly damaged from the outside.

Aggregate predicted losses -- figures such as tens of billions of dollars of property loss, up to about 10,000 fatalities, or a few thousand buildings destroyed or rendered unfit for occupancy -- seem overwhelming. See Figure 3 in Chapter 1. Individual odds are much better, however. Most buildings would experience property damage up to no more than 25% of their replacement cost even if subjected to very severe shaking. In large scale medical exams the statistics indicate that most individuals are found to be in fair or good health -- the problem is to single out those few who need treatment. With buildings where their "seismic health" is concerned, the corresponding problem is to identify those few that would collapse or be heavily damaged in a future earthquake.

Figure 23

Aerial Photo of Santa Barbara

Photo credit: Security Pacific National Bank photograph collection, Los Angeles Public Library

The following brief explanations touch upon some of the most prominent categories of seismically weak buildings in California. To pursue this topic beyond these generalizations, the best advice is to consult a structural engineer. (See Chapter 4 for a description of types of engineers.) The following explanations are excerpted from "Earthquake: What to Do - and Why," by Robert Reitherman, **California Geology**, March 1982.

Old Masonry Buildings

Structures that were built before earthquake code regulations were adopted (generally pre-1933 in southern California and pre-1948 in the Bay Area, but with much local variation) are seismically suspect, and the older masonry buildings are especially notorious. In addition to having unreinforced walls of brick, block, stone, or adobe, which are easily cracked and fragmented and very hazardous when they fall, the floors and roofs of these buildings are typically only loosely connected to the walls. Retrofit measures to strengthen these buildings include the use of steel hardware to tie the walls to the floor or roof and the addition of an interior or exterior layer of steel framing or reinforced concrete to the masonry walls to increase their strength. Based on a study by an engineering firm for the Los Angeles building department, the connection retrofit, at an average cost of about $1.50 per square foot of building area, is typically much less expensive than the strengthening of the entire wall, which costs approximately $6 to $12 per square foot. Sometimes only one type of upgrading is required, sometimes both, (Ref. 10).

Tilt-ups

These ubiquitous commercial and industrial buildings are named for their manner of erection: walls are of reinforced concrete poured flat on the ground, then tilted up vertically when hardened. The earthquake problem of this construction class lies not with the wall itself but rather with a common connection detail, which is similar to the weak way in which floors or roofs of old masonry buildings are connected to the walls, (even though the tilt-ups with this problem are of much more recent vintage). The addition of steel bolts to connect walls to floor or roof is generally less expensive than in the case of brick buildings, and these retrofit connections can prevent the tilt-up from becoming a "tilt-down" during an earthquake.

House-over-garage

In this category, the weakness is caused by the overall configuration of the structure, rather than its construction details. When the front of the ground story of a house or apartment building is left open for parking, the lack of solid walls can create a fatal flaw, which the earthquake will seek out. A steel frame around the garage openings can be designed to provide sufficient horizontal strength, but wood posts and beams do not have significant lateral resistance. In cases where sufficient side yard clearance exists, however, a solid wall (shear wall) of wood frame construction can be added to form a buttress.

Other problems concerning the overall shape of a building and the location of its internal structure include the soft story (a weak ground story, compared with upper stories, because of greater height or fewer walls or columns at the entry level), L-shaped and other complex-plan buildings, and buildings with an imbalance in the location of solid walls (Ref. 11)

Mobile homes

While the wooden box constituting the structure of a mobile home is earthquake resistant, the typical method of mounting the mobile home at its site makes this type of construction especially earthquake vulnerable. Mobile homes are damaged about twice as much in earthquakes as ordinary wood frame houses (Ref. 12).

The solution, in engineering terms, is quite simple, and a number of braced foundation support designs are available that can be used for an existing mobile home. In political terms, however, the solution to the problem has been much more difficult, because mobile home standards are separate from the building code. Because of the way in which mobile homes behave in earthquakes -- by falling off their jacks the way an auto raised up on blocks would topple over if shaken -- gas lines often break, and the fire hazard is higher as well.

Non-ductile Reinforced Concrete Frame Buildings

In this type of construction, there are no load-bearing walls and the columns and beams (the frame) hold up the structure and resist horizontal earthquake forces. Unfortunately, a number of buildings constructed from the fifties up to the mid-seventies, when the building code caught up with the problem, are now known to have arrangements of reinforcing bars that produce brittle, rather than ductile, or tough, performance. Instead of merely being permanently bent out of shape or experiencing controlled cracking, these non-ductile concrete frames can come apart and collapse when overstressed by an earthquake, as happened to four apartment buildings of 10-story height in the 1967 Caracas, Venezuela earthquake. The solution to this defect is almost never easy, and involves the construction of new solid walls (shear walls) sufficient to withstand the total forces, which makes the frame's strength moot, or the strengthening of columns, beams, and joints throughout the structure.

Pre-cast Concrete Buildings with Pre-existing Distress

A pre-cast building is composed partially of reinforced concrete or prestressed concrete beams, planks, or columns that were poured and fabricated at a factory and then shipped to the site and erected. Reinforced concrete is reinforced with steel bars with deformations or a knobby texture to increase their bonding with the concrete; prestressed concrete's steel is in the form of cables which are tensed or stressed inside the concrete. Plain or unreinforced concrete has no major uses in construction because without steel it is too weak.

Many pre-cast buildings are adequately earthquake resistant. "Pre-existing distress" is added to the subheading above to single out the structure which is probably visibly cracking because of incompatible shrinking in the size of its different portions.

Another possible weakness is the sometimes brittle way in which the pieces that were trucked to the site are connected together after being lifted into place by a crane.

Pre-cast building failures were conspicuous in Anchorage in the 1964 Alaska earthquake.

8. References

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5. Henry Spall, "Charles F. Richter--An Interview," **Earthquake Information Bulletin,** January-February 1980, Vol. 12, No. 1.

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8. Robert A. Huttenback, **Policy on Seismic Hazard Reduction,** Office of the Chancellor, University of California, Santa Barbara, 1980.

9. William H. Steinmetz, "How A Campus Handles An Earthquake Disaster," 26th National Conference on Campus Safety, University of Michigan, Ann Arbor, 1979.

10. Wheeler and Gray, Consulting Engineers, "Cost Study Prepared for Structural Strengthening Using Proposed Division 68 Standards," Los Angeles Department of Building and Safety, May 1980.

11. Christopher Arnold and Robert Reitherman, **Building Configuration and Seismic Design: The Architecture of Earthquake Resistance**, John Wiley and Sons, New York, 1982.

12. K.V. Steinbrugge, "Earthquake damage to mobile homes in California," **California Geology**, v.33, no. 10, 1980.

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9. Annotated Bibliography

This brief bibliography can direct the individual who requires more detailed information to other bibliographies, such as those contained in references 5, 7, and 14, and thus this list is not meant to be comprehensive. Almost all of these published works or other papers on this subject are technical in nature, which was why this booklet was intended to fill the gap for the non-engineering-oriented audience, but the following is provided for the architect or engineer who may refer to this booklet. In the opinion of the author, architects or engineers attempting to competently provide in-depth services with regard to the seismic design and analysis of nonstructural items should make themselves familiar with most of the following references.

1. Army, Navy, and Air Force, Departments Of, **Seismic Design For Buildings**, Washington, D.C., Superintendent of Documents, 1982.

Commentary and calculation examples are provided; see especially Chapter 11. Generally parallels the UBC, but written as a design aid rather than a code. Portions of the book were written by S.B. Barnes and Associates, and John A. Blume and Associates (now URS/Blume Engineers), which are Los Angeles and San Francisco structural engineering firms respectively.

2. Ayres, J.M., T.Y. Sun, and F.R. Brown, "Nonstructural Damage to Buildings," **The Great Alaska Earthquake of 1964: Engineering**, National Academy of Sciences, Washington, D.C., 1973.

3. Ayres, J.M., and T.Y. Sun, "Nonstructural Damage," **The San Fernando, California Earthquake of February 9, 1971**, National Oceanic and Atmospheric Administration, Washington, D.C., 1973.

These are the first two comprehensive post-earthquake damage analyses devoted to the topic of nonstructural components. The authors are mechanical engineers.

4. Dowrick, D.J., **Earthquake Resistant Design: A Manual for Engineers and Architects**, John Wiley & Sons, New York, NY, 1977.

A comprehensive text, with two chapters ("Earthquake Resistance of Services" on mechanical-electrical components, and "Architectural Detailing for Earthquake Resistance,") directly relevant. Dowrick is a senior engineer with Ove Arup Partners, a British engineering firm engaged in worldwide consulting, and thus his book has an international perspective with references to many different codes.

5. Holmes, William T., "Nonstructural Components," EERI Seminar Proceedings: **FIX'EM: Identification and Correction of Deficiencies in the Earthquake Resistance of Existing Buildings**, Earthquake Engineering Research Institute, (EERI), Berkeley, CA, 1982.

This lecture outline contains a complete bibliography and comprehensively itemizes the subtopics within the subject of nonstructural earthquake protection. Holmes is a structural engineer with Rutherford and Chekene, a San Francisco civil and structural engineering firm, which has been involved with existing building nonstructural retrofits and new construction designs, especially with hospitals. The Earthquake Engineering Research Institute is a multi-disciplinary professional association, which publishes an extensive newsletter-magazine and post-earthquake damage reports.

6. International Conference of Building Officials, **Uniform Building Code** (especially the "Earthquake Regulations" of Chapter 23), and **Uniform Building Code Standards** (No. 27-11, Steel Storage Racks, and No. 47-18, Metal Suspension Systems for Acoustical Tile and for Lay-In Panel Ceilings), Whittier, CA, 1982.

New editions of the Code and Standards are issued every three years. The rationale behind the earthquake regulations (which is as important as the specific regulations themselves) is contained in the booklet by the Structural Engineers Association of California listed below (Ref. 12). The International Conference of Building Officials is a non-profit model code organization.

7. McGavin, Gary L., **Earthquake Protection of Essential Building Equipment: Design, Engineering, Installation**, John Wiley & Sons, New York, NY, 1981.

A book-length treatment of the subject. Especially appropriate for large, complex projects such as hospitals or power plants. McGavin is an architect with Ruhnau-Evans-Ruhnau Associates, a Riverside, California, architecture and planning firm.

8. Office of the State Architect, Structural Safety Section, **Interpretation of Regulations #IR 23-7, Title 24 California Administrative Code: Anchorage of Non-Structural Building Components and Hospital Equipment**, in development, Sacramento, CA, 1983.

The regulations legally pertain only to essential nonstructural items in California hospitals, but the regulations can provide a guide as to anchorage engineering of especially essential items for other types of buildings. The Office of the State Architect has been centrally involved in earthquake code regulations since the 1933 Long Beach earthquake.

9. Schiff, Anshel J., **Pictures of Earthquake Damage to Power Systems and Cost-Effective Methods to Reduce Seismic Failures of Electric Power Equipment**, Purdue Research Foundation, West Lafayette, IN, 1980.

This is one of the few works in this subject area that is readable by the non-technical audience. Engineering appendix and bibliography also included. Schiff is a mechanical engineering professor at Purdue University.

10. Sheet Metal Industry Fund of Los Angeles and Plumbing Piping Industry Council, Inc., **Guidelines For Seismic Restraints of Mechanical Systems and Plumbing Piping Systems**, Los Angeles, 1982.

These typical working drawing details for the anchorage of ducts, pipes, and mechanical equipment are written to comply with the State's seismic regulations regarding hospitals, rather than the Uniform Building Code's provisions for ordinary buildings, and thus they meet high reliability and force level standards. The Sheet Metal Industry Fund of Los Angeles is associated with the Sheet Metal & Air Conditioning Contractors' National Association, Inc. The booklet was prepared by Hillman, Biddison and Loevenguth, Los Angeles structural engineers.

11. Karl V. Steinbrugge, **Scenarios For Earthquake Related Problems At Computer Installations Used By Financial Institutions**, Task Force on Earthquake Preparedness, California Seismic Safety Commission, Sacramento, CA, September 1982.

This paper discusses the general vulnerability of the California financial industry's computer facilities, provides factors for estimating earthquake damage and computer service outages, and discusses the major sources of damage and sensitivity to other service outages. Steinbrugge is a structural engineer, first chairman of the California Seismic Safety Commission, and a frequent on-site observer and analyst of the effects of damaging earthquakes.

12. Structural Engineers Association of California, **Recommended Lateral Force Requirements and Commentary**, San Francisco, 1980.

Also known as the Blue Book, the "Requirements" portion of this periodically updated booklet is adopted into the Uniform Building Code almost verbatim, while the "Commentary" explains the assumptions, limitations, and caveats which must be understood for the regulations to be used intelligently. The Structural Engineers Association of California has been active in the development of seismic code regulations, standards of practice, research, and testing for several decades.

13. Veterans Administration, Office of Construction, **Study To Establish Seismic Protection Provisions For Furniture, Equipment & Supplies For VA Hospitals**, Washington, D.C., 1976.

This booklet shows typical nonstructural damage inside a hospital, illustrates restraint techniques with cost estimates for a variety of types of hospital equipment and furnishings, and includes a brief engineering appendix. Stone, Marracini, and Patterson, a San Francisco architec-

tural firm, with the assistance of Rutherford and Chekene, a San Francisco civil and structural engineering firm, prepared the booklet. Relevant for buildings other than hospitals especially if laboratories are present.

14. Yancey, C.W.C., and A.A. Camacho, **Aseismic Design of Building Service Systems: The State of the Art**, National Bureau of Standards Technical Note 970, Washington, D.C., 1978.

A literature survey and review of present practice, especially with regard to the specific mandatory regulations of building codes. The National Bureau of Standards, a federal bureau, has been involved with earthquake research, and post-earthquake damage reports.

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