SUMMER SEISMIC INSTITUTE FOR ARCHITECTURAL FACULTY

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This Institute was convened for the purpose of bringing concerns of earthquake safety more broadly into the architectural community. Participants were faculty members from schools of architecture throughout the United States. Objectives of the Institute were to present basic seismic knowledge to the participants, to allow them an opportunity to apply this gained knowledge, and to develop strategies for integrating this knowledge into the curricula of schools of architecture across the country. Fourteen lecturers considered such subjects as the geological hazards of earthquakes, soils/structure interaction, earthquake risk and public policy, concepts of land use and urban planning for earthquake disaster mitigation, structural concepts related to earthquake forces, conceptual design of nonstructural systems to withstand earthquakes, architectural planning and design strategies for earthquake-resistant buildings, the challenges of seismic renovation and rehabilitation, and the impact of architectural design decisions on the performance of buildings during earthquake activity. A presentation by the John A. Blume Center at Stanford University and a demonstration of the "shake table" allowed participants to view the effects of earthquake forces on buildings.

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AIA RESEARCH CORPORATION
October, 1977

CONTENTS

INTRODUCTION

SECTION 1 INSTITUTE PAPERS

SECTION 2 STRATEGIES

SECTION 3 RESOURCES

INTRODUCTION

The AIA Research Corporation received a grant from the National Science Foundation (RANN) to hold a Summer Institute for seismic building design at Stanford University in California from August 7-12, 1977. The purpose of the Summer Seismic Institute was to bring concerns for earthquake safety more broadly into the architectural community. The Summer Seismic Institute participants were faculty members from schools of architecture throughout the United States.

Participants in the Summer Seismic Institute were exposed to a body of basic knowledge concerning the interaction of earthquakes and the built environment. One principal aim of the Institute was to draw on the experience and skills of the architectural teaching community in developing ways to approach the educational issues involved in seismic safety design. The faculty assisted us in finding ways to introduce earthquake concerns into the design curriculum, and encourage the dissemination of seismic building design knowledge to architectural students.

The Institute fostered an awareness and concern among architectural faculty members about how planning and design affect building performance and life safety under earthquake conditions. The Institute addressed architectural issues related to seismic building design, examining seismic questions from an architectural viewpoint. The program emphasized what the architect can do to design earthquake resistant buildings and how this knowledge can be applied to educating future professionals.

The Institute involved six days of concentrated work and thought, interspersed with free time for individual pursuits. The Institute commenced with presentations from some of the country's most noted authorities on various aspects of seismic safety of concern to architects.

Fourteen lecturers considered such subjects as the geological hazards of earthquakes, soils/structure interaction, earthquake risk and public policy, concepts of land use and urban planning for earthquake disaster mitigation, structural concepts related to earthquake forces, conceptual design of nonstructural systems to withstand earthquakes, architectural planning and design strategies for earthquake resistant buildings, the challenges of seismic renovation and rehabilitation, and the impact of architectural design decisions on the performance of buildings during earthquake activity. A presentation by the John A. Blume Center at Stanford University and a demonstration of the "shake table" allowed participants to view the effects of earthquake forces on buildings.

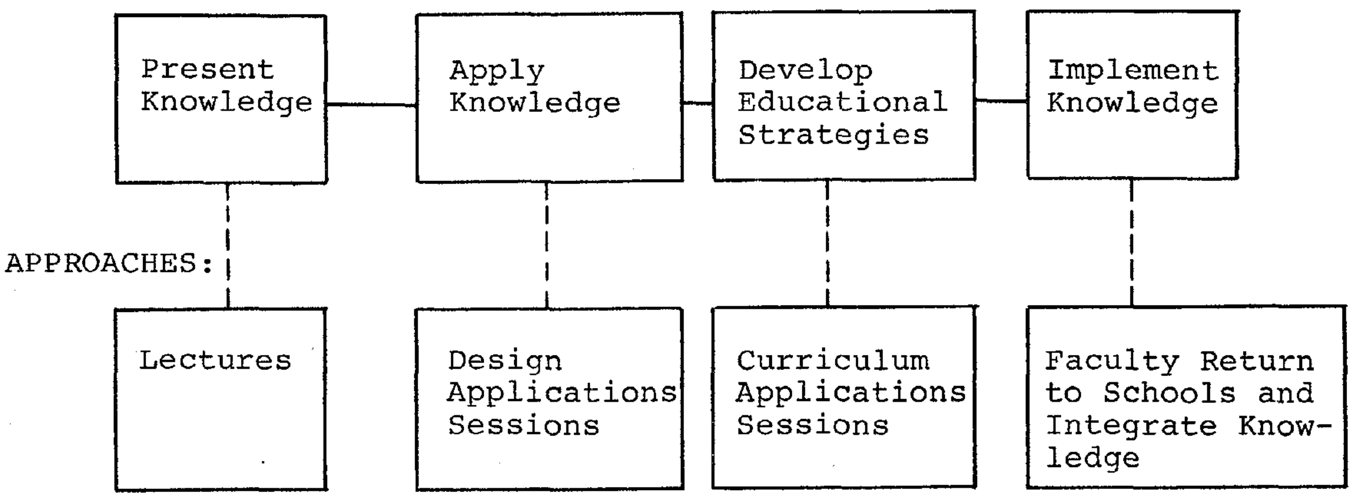
A major purpose of the Institute was to develop strategies and concepts for applying seismic concerns to the range of topics taught in schools of architecture. Participants were given the opportunity to apply the knowledge gained from the lectures to specific design problems during the Design Applications sessions. Recognizing the importance of implementing this knowledge into architectural curricula, the Curriculum Applications sessions allowed the participants to identify, discuss and develop recommendations for incorporating seismic knowledge into architectural schools.

During the Design Applications and Curriculum Applications sessions, the participants were divided into four teams. The group instructors presented certain information, posed problems, answered questions and assisted the participants in identifying certain solutions and concerns.

Course materials assembled and prepared by AIA/RC included a manual and workbook, a set of slides illustrating areas of study, and related publications. This material, along with the information and knowledge gained by participants, hopefully yielded a body of educational materials and methods for use by faculty members in developing ways to teach students and fellow professionals about seismic design issues.

The objectives of the Institute were to present basic seismic knowledge to the participants, to allow them an opportunity to apply this gained knowledge, and to develop strategies for integrating this knowledge into the curricula of schools of architecture across the country. Achievement of the ultimate goal of the Institute relies on the actual implementation of seismic knowledge in the schools by the participants themselves.

OBJECTIVES:



This report includes papers based on the lectures given at the Institute; a section describing and displaying the strategies developed at the Institute for incorporating seismic design into schools of architecture; and a final section that includes a listing of resources that are available and responsive to architectural faculty as well as practitioners.

AGENDA FOR THE 1977 SUMMER SEISMIC INSTITUTE FOR ARCHITECTURAL FACULTY

TIME	SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
8		8:00 BREAKFAST 8:30	8:00 BREAKFAST 8:30	8:00 BREAKFAST 8:30	8:00 BREAKFAST 8:30	8:00 BREAKFAST 8:30
9		9:00 LECTURE 1: GEOLOGIC HAZARDS CLUFF 11:35	9:00 LECTURE 4: LAND USE PLANNING MADER 11:35	9:00 LECTURE 6: STRUCTURAL CONCEPTS DEGENKOLB 11:35	9:00 LECTURE 9: EXISTING BUILDINGS BRESLER 11:35	9:00 LECTURE 11: PUBLIC POLICY STEINBRUGGE 10:45
10						
11		11:45 LUNCH 12:30	11:45 LUNCH 12:30	11:45 LUNCH 12:30	11:45 LUNCH 12:30	11:00 CURRICULUM APPLICATIONS 12:00
12		12:40 LECTURE 2: SEISMIC REGISTRATION CRAWLEY 3:00	12:40 LECTURE 5: SOILS/ STRUCTURE DONOVAN 3:00	12:40 LECTURE 7: NONSTRUCTURAL SYSTEMS MERZ	12:40 BLUME CENTER DEMONSTRATION 2:15	12:15 LUNCH 1:00
1						1:15 SEISMIC RESEARCH SCALZI 2:15
2					2:30 LECTURE 10: SEISMIC RESTORATION WORSLEY	2:30 CURRICULUM APPLICATIONS 4:00
3	3:00 REGISTRATION	3:15 LECTURE 3: ARCHITECTS ROLE BOTSAI	3:15 LECTURE: STRONG MOTION INSTRUMENTATION MATTHEISEN	3:00 LECTURE 8: ARCHITECTURAL COMPONENTS FISHER		
4		4:45 INTRODUCTION TO APPLICATIONS 5:45	4:45 DESIGN APPLICATIONS 1 5:45	4:45 DESIGN APPLICATIONS 2 6:15	4:15 DESIGN APPLICATIONS 3 5:45	ADJOURNMENT
5	5:30 RECEPTION					
6	6:30 DINNER 7:30	6:30 DINNER 7:30		6:30 CODES: ZACHER DINNER 7:30	6:30 PREDICTION: RALEIGH 7:30	
7	INTRODUCTION					
8						

SECTION 1

INSTITUTE PAPERS

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THE ARCHITECT'S ROLE IN SEISMIC DESIGN

Elmer E. Botsai, FAIA

CONTENTS

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THE ARCHITECT'S ROLE IN SEISMIC DESIGN

PRESENT ROLE OF THE ARCHITECTURAL PROFESSION

What is the architectural profession's present role in the area of seismic design? Currently the input and role of the architectural profession, including the architectural education system has been minimal. In fact when disaster mitigation is discussed the architectural profession is usually not even considered. Our present state is that the federal government and other organizations have noticed the profession is becoming interested in seismic research.

Of the entire profession, architects in California have probably had the most seismic involvement and activity. Architects have been involved in the past Governor's Joint Committee on Seismic Safety, the California State Building Standards Committee, the California Seismic Safety Commission and the Office of the State Architect. But as a profession most of our involvement has been limited to the few individual architects who have been concerned enough to serve on these committees and organizations. That is not representation by the profession.

The first truly profession wide involvement has just started. The Joint Committee on Hazardous Buildings has been formed jointly by the California Council AIA and the Structural Engineers Association of California. This committee is composed of members of both organizations who speak to policy issues relating to the earthquake problem of existing buildings.

The second involvement of the profession has been the earthquake program at the AIA Research Corporation. These earthquake projects rely heavily on using and building on the involvement of the profession. Past projects include Architects and Earthquakes, Architects and Earthquakes: Research Needs, and a visit to the Guatemalan Earthquake by a team of architects. Current projects include Seismic Design for Police and Fire Stations and this Institute.

Another recent architectural involvement is the Applied Technology Council (ATC), which was the first attempt to put together a comprehensive attack on the issue of earthquake standards for building design. All concerned disciplines were involved including architects. I think the project will deliver a sizable body of knowledge that will lead to some very serious debates in the design community for the next few years.

At present seismic research has been almost entirely the domain of engineering educators and those practicing structural engineers who have been involved and interested in seismic design. I don't believe this is to the best interest of all concerned. I think anytime any body of knowledge is solely limited to one discipline there is a chance for that body of knowledge to be perverted when it comes to political decisions.

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WHY SHOULD THE PROFESSION BE CONCERNED?

Why should the architectural profession be concerned about its past and future involvement in seismic design and research? One reason is that seismic design is a major element of total life safety. Earthquakes give less warning, have shorter duration and can have more intensive results than any other natural disaster. There is no time frame during the actual event when the public can respond. Earthquakes happen with such infrequency that it is very easy to ignore the destruction potential. Yet when an earthquake occurs a great cry of lack of competance can be laid upon the design professions for failure to recognize this potential and lead the public properly in the design of the built environment. As such it is fundamental that the architectural profession become involved and concerned with seismic safety.

A second reason is the fact that the architect's input governs to a very large extent the building's success or failure under seismic conditions. These early decisions in the fundamental design process can have more to do with the building's safety than any other issue in the design process. The architect plays the major role in determining the building's shape, form, configuration, basic structural system, materials, and nonstructural systems and components. As an example it is generally the architect's decision that sets up such things as eccentricity, improperly mixed systems, etc. The engineer within any reasonable economic limits can at most reduce the damage potential of a design concept that still remains seismically poor. A third reason the architect needs desperately to be concerned and involved in seismic design is the large amounts of building damage and life loss/injury attributable to nonstructural building systems. These components and systems, such as glazing, facades, interior walls, etc. can and have amounted to damage in excess of 70% of the building's total worth during previous earthquakes.

The engineer cannot nor should he be asked to be responsible for the seismic safety of the total building. What about even structural system failures? How many are really failures of architectural concepts? I don't know many times when a major structural failure is really not an architectural design failure. Can it be a structural failure when the architect designs a building that allows the structural engineer very little latitude or economic choices in designing a truly earthquake resistant structural system?

So whose responsibility is it when a building collapses or suffers severe damage during the earthquake? I think it is the responsibility of the design team, not any given discipline. Therefore we, as a profession including we as educators, have an obligation to be concerned about this issue.

Thus proper seismic design requires an integrated team. This means closely integrated from the very conception of the building. All to often, architects consider themselves the unique supreme leader and make decisions which are held closely until consultants are called in to "do their job." I think that's wrong. I think if an architect clearly understood siesmic design and was able to relate to the engineering consultants including the mechanical and electrical, then you would have a truly integrated operation. To do that, the architect must be able to communicate with the engineering profession but communication is a two-way operation. The architect must be able to hear the engineering profession and the architect must be able to want to hear the engineering profession.

It is also the architect's responsibility to clearly articulate seismic exposure and potential risk factor to the owner or client. But if the architect is to do that, then the architect must be conversant with the seismic risks and the damage potential. The architect must understand the various design levels and the economic considerations related to those various design levels. The architect must understand the damage potential to the various components of the building. Only then can the architect articulate those choices to an owner so that the owner has a chance to make a decision based on some rational information.

I think there is one other additional aspect of property damage that the architect must face. As a society, how much of our resources, including money and energy needed to produce building components and materials, can we afford to risk in an earthquake? Can we afford to continue the traditional first cost syndrome, and just say we'll replace it? I think not. The cost of energy is already going out of sight, and we are all very much aware of its ramifications. In the future it will be translated directly to the cost of construction. We are faced with a capital investment shortage of some 800 billion dollars in the next few decades. How much of these resources can we afford to risk? I think as a profession we have to make an attempt at answering those kinds of questions and try to offer the public some guidance.

ROLES AND RESPONSIBILITIES OF THE PROFESSION

The architect's responsibility to our society for the protection of life and property is many faceted. One is the development of building codes and standards. This cannot be entirely left to other disciplines. Increasingly the approach has become more sophisticated and complex. Codes and standards are not an abstract theoretical issue. They are too important to be left entirely to theoreticians. We need the input of designers (architectural and engineering) who understand the total systematization of buildings and their interrelationships. We need people who are willing to take a rational approach to compromise. That is what codes and standards are all about. We don't have the resources and money to protect all the buildings against all the seismic risks for all the people, nor do I think it would be appropriate utilization of resources. I think that the architectural profession is uniquely qualified to balance these various issues, and at least make judgements for people to consider. I do not think the architectural profession should have any more power than any other profession, but their input is important.

The education of government should be a very high priority on our calendar. At the local level, be it city or region, we need to insure that proper code adoption procedures are instituted and followed, and that these procedures allow for the examination of all available information. As a profession, we need to get involved in the educational process of the lawmakers to discuss these options openly and candidly. We need to urge the states to research their real needs, not necessarily their political needs, but their needs for disaster mitigation.

And finally, we need to establish minimum standards for the profession. I personally do not know what these standards are, but I don't think they include architects relying on calculations. The basic issue is not good seismic design but seismic good sense. They should intuitively know what good seismic sense is. If they have to relate to a computer, a slide rule or a piece of paper and pencil, I think they are in serious trouble. What I do think they must know, is what happens to a building under lateral forces. They must be able to visualize it in their mind and maybe even draw it out without knowing the exact engineering calculations. They should also know what happens to every component in the building when it interacts with the structure during an earthquake. That is what architects need to know about and it should be second nature to them. It should be the same type of intuition we have in dealing with space, form, volume, color - all the design tools that we use when we design.

The profession should also become involved in urging the proper level of government funding for earthquake research. We should urge the coordination and dissemination of the seismic research results and information. We should also assist the federal government in the development of rational earthquake policies based on this research.

Another role involves the education of the financial institutions of this country. These financial institutions have an enormous impact upon this country's physical plant. They can be educated to recognize that as a major policy-maker in this country they have a social responsibility to be aware of the earthquake damage potential. They can also be approached on their own vested interests. What is the risk factor, in terms of mortgage monies, after a destructive earthquake? What is the risk factor on their own earthquake insurance? What is the risk factor on their own portfolios? I think our profession, because we represent the building owners, should be the ones to take these questions to them as a public responsibility.

The profession also must educate the public, and this is probably the most difficult task of all. We must reach the public with a recognition that an earthquake is a finite force whose damaging effects can and do happen outside California and with major consequences. We must educate the public so there is not an overreaction after an earthquake and thus to maintain a sense of rationality in the lawmaking process after the incident.

ROLES OF COMPONENTS OF THE PROFESSION

What are the appropriate roles for the components of our profession - the AIA, the educational system, and the individual architect? I think the AIA needs a staff to establish proper standards of performance for, not only building design and construction, but for professionals. I think this will be very difficult to do because all the various elements involved will have to be recognized and dealt with. To do less than this, is not fulfilling our public charge to exercise our particular expertise which, by law, is greater than the public knowledge. The Institute has a responsibility to raise the public and government awareness. We have the ideal mechanism to lobby at the various government levels. We have local, regional and state components, and the headquarters in Washington, D.C.

We need to get into the seismic education of our existing profession, to develop an awareness of need. In addition, we must be in a position to deliver education when our profession starts demanding to learn. We now have our AIA continuing education programs and they are starting to work down through all levels. They certainly need more sophistication, more availability, but we have a start.

And finally the AIA has to monitor the development of the profession. Unless we can monitor, we cannot find out what areas have knowledge gaps, when we are ready for new levels of knowledge, when new areas of concern emerge, and what and how much the profession can absorb. We have to involve architects in seismic research, and the AIA Research Corporation cannot do it alone. We can be very proud and pleased with what we've done recently. It has all been applied research and I suspect that we will have our hands full for the next few years in applied research. But sometime in the future, I would hope to see our profession start getting into basic research.

We must do research by architects, for architects, that is responsive to architects. I think there is only so much absorption, with our training and background, that we can take from the engineering profession. Presently there is so much information and knowledge, we will be able to learn from them for many years, but eventually we will have to start finding our own answers to our own problems and needs.

What are the responsibilities of the architectural educational system? I think the future professional should come out of our shcools with an awareness of the seismic responsibility the profession must share. I think they need to have an intuitive understanding of seismic forces and how buildings, as total systems, react to earthquakes. They should understand the interaction and reaction of all the integral systems of the building and their impact on the building when one is destroyed or damaged. They should understand the impact both in terms of the building and the occupants. They will need an understanding of the basic design decisions and their impact upon the building's performance during an earthquake. I think we have an obligation to deliver those kinds of students.

I would also like to see the schools develop programs of research in seismic design. I think this is a proper role for schools of architecture. They should become the leaders in architectural seismic design research. They can become the respositories of knowledge; an historical purpose of the university system. I don't think we've done this anywhere in architecture, let alone in seismic design. As a final step the schools will need to develop methods for distributing this knowledge and make it available to the architectural profession and public. This would mean the schools would have to assist, and in some places lead, the AIA in the education of our existing professionals.

Finally we come down to the individual practicing architect, the most important and indispensable link in the whole chain. We must reach and modify the individual architect's concern for seismic design, while concurrently increasing the architect's ability to respond to this concern. It is the practicing architect who designs the buildings by which we, as the profession, will be judged. All the theoretical knowledge in the world is not worth anything if we cannot create buildings in which people live, work and play that will offer a degree of safety during an earthquake. These buildings will be a measurement of our concern for public safety.

GEOLOGIC CONCEPTS OF EARTHQUAKES

Lloyd S. Cluff

CONTENTS

* edited from lecture transcripts

GEOLOGIC CONCEPTS OF EARTHQUAKES

CAUSES OF EARTHQUAKES

Development of the theory of plate tectonics has greatly increased our understanding of earthquake occurrence. The theory asserts that the upper mantle of the earth is made up of internally rigid plates which slowly slide independently over the interior of the earth. The movement of these plates is caused by the molten material of the earth's interior pushing through the surface crust and then cooling to form new crust. As new crust is formed it is pushed away along these spreading centers in opposite directions and thus we have two continents moving farther and farther apart. The spreading rates range on the order of a few centimeters per year to as much as ten centimeters per year.

We have been able to find proof of this theory because of the fact that every few hundred thousand years the earth reverses its magnetic field. The molten volcanic material that comes up along the faults solidifies recording the magnetic direction of the earth's crust. When the earth's magnetic field is reversed and the molten material is solidified, we have a record of these magnetic reversals. These reversals are not completely cyclic, but they do occur. So we can count back in time millions of years and see how often the shift has occurred; thus seeing that the rocks have been pushed in opposite directions. That is a simplified explanation of the driving force of the plates.

As an example of plate movement, the South American Plate is moving relatively westward with respect to the oceanic plate. There was a collision between the two plates. The continental mass, being much thicker and relatively less dense, tends to ride up while the oceanic crust, much denser and thinner, tends to underthrust the continental mass. We then have an area of subduction where part of the earth's crust is consumed underneath the continental mass and the collision creates a very spectacular topographic feature, the Andes of South America.

This is something that has been a total revolution in the geologic knowledge of what causes mountain ranges. It is interesting to go back and read some of the text books that were written only fifteen years ago; they are so complex most people had a difficult time understanding mountain building processes. This has simplified the process and made it very easy to understand that the highest mountain ranges in the world are where we have these plate collisions. That is the reason the west coast of South America has such high, spectacular mountain ranges.

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This is also true of another part of the earth's crust, the Indian Continent. India at one time was a continent by itself. As it drifted north it collided with Asia. Thus two continental masses collided, rather than an oceanic and continental mass. The Indian mass being thinner and not as large as Asia, was consumed and is being consumed underneath the Asian continent. That is the reason we have the highest mountain ranges in the world, the Himalayas, across the north part of India. This whole process is not only a well accepted hypothesis, in many places we have absolute proof that this is what happens. We can actually show the time intervals involved in the rates of movement along these plates.

Another plate boundary, this one where the plates slip along faults releasing earthquakes, is the San Andreas Fault. The San Andreas Fault is a zone a few thousand feet to as much as two miles wide in some locations. When the geology on one side is compared to the geology on the other, it is completely mismatched. You would have to go, depending upon the age of the materials, more than two hundred miles to match up the geology from one side to the other. The west side of the block is moving northwestward with respect to the east side. Since San Francisco is on the east side and Los Angeles is on the west side, an interesting and quite disconcerting phenomenon is happening. In geologic time, Los Angeles and San Francisco will be juxtaposed to one another. There will then be an argument between the two cities as to who is the suburb of whom. However, San Franciscans can laugh with glee in that, in time, Los Angeles will continue to work northward to be finally subducted down into the Aleutian Trench.

Of course, that is speculation throughout geologic time, and it would take about 50 million years for that to be accomplished. Nevertheless, it does demonstrate that we are next to these very large faults, and that there is a complete acceptance within the scientific community that earthquakes are caused by slips along faults.

So the issue then becomes, in terms of identifying where quakes occur, identifying not only the locations of where historic earthquakes occurred, but also identifying those faults that are potentially capable of generating earthquakes. There are geologic aspects that allow us to look at different types of faults and judge the potential size and frequency of earthquakes which might be generated along those faults and what the effects of those earthquakes might be. A theory that was developed by Ree after the 1906 San Francisco earthquake is called the elastic rebound theory. Strain accumulates in the earth's crust and if that strain builds up, we get an elastic bending of the earth's crust. The strain continues to gradually build until the elastic limit of the rocks and the earth's crust are reached, at which point the fault slips. The release of the strain energy that is stored elastically in the earth's crust is the energy that is released in the form of an earthquake. It is really that simple. It is interesting to note that this hypothesis, which came from studies of the 1906 earthquake along the San Andreas Fault, was not accepted worldwide until just a few years ago. Thus strain builds up in the earth's crust, and when the elastic limit is reached the fault slips and releases the strain energy in the form of an earthquake.

Now, we need to know where these faults are and which faults are going to slip. That is the geologist's role, because the earth's crust is shattered with thousands of faults, and nowhere in the earth do you find an intact block. You always have planes of weakness, of faults, and so it becomes very interesting trying to distinguish between those faults that have the potential for slip when strain is accumulating in the earth's crust and those that do not -- in other words, an active fault or an inactive fault. And that problem is a very controversial one; a great many innovative techniques and new ways of examining this have been developed in the last few years. What we find is that there is a direct relationship between the rate of strain accumulation in the earth's crust, the length of the fault, or at least the length of the fault that ruptures during an earthquake, and the amount of displacement that occurs. This can be directly compared with the size of the earthquake that is capable of being generated at those locations. In many places, particularly in California where we've devoted much more effort than probably anywhere else in the world, with the exception of probably Japan and maybe some parts of New Zealand, we can really quite accurately predict where these active faults are. There are some surprises in terms of active faults being discovered where none had been known prior to this time. Just in the last ten years, we have discovered in the Bay area six new active faults. These are faults that are potentially capable of generating damaging earthquakes --not as large as the San Andreas but, nevertheless, certainly important from the standpoint of building design.

The epicenter of the earthquake is the point on the earth's surface above the focus, the focus being where the first slip starts on the fault. An earthquake is triggered when a slip expands in all directions along the linear plane and length of the fault. The size of the displacement determines the size of the earthquake and the duration of the shaking. So what actually occurs is, as this rupture continues for a few seconds to, in the longest cases, more than a minute, really a series of earthquakes.

I find it of interest, in examining the potential effects of earthquakes in terms of locating and designing facilities, to categorize earthquake effects into the four following categories:

- The specific damage that is directly related to faulting itself;

- The specific damage with respect to the shaking, or ground motion during the earthquake;

- The specific damage that is related to ground failure, which is a direct result of ground motion; and

- The specific damage related to Tsunami, a seismic sea wave or a large wave on the ocean that is generated by the earthquake.

SURFACE FAULTING

By far the greatest effect that we have to worry about in terms of damage, in almost all earthquakes, is the shaking, or ground motion. Even though faulting and landsliding are extremely spectacular, particularly from the geological point of view, the ground motion is the primary concern and the main factor in earthquake-resistant building design. Nevertheless, one can not ignore these other hazards if a structure is going to be located in an area where there is a potential for liquifaction, landsliding, earth differential settlement, or if it is located directly across the primary fault causing the earthquake.

In the various areas where we have active faults, we find that the land is extremely valuable. Consequently, we want to utilize that land as much as possible and still avoid high hazard areas. So one must determine what degree of risk is acceptable for the various types of structures. Some structures can be safely located a few tens of feet from a fault. Others, such as high-rise buildings, should not be within a few hundred feet because they probably would not withstand even minor deformations that occur very close to the fault. So, from the standpoint of the hazard, it is not the proximity to the fault that counts. It is important, there is no question about it, but when one takes all the factors into consideration, the degree of shaking clearly can be greater at a distance from the fault than near the fault. Of course, that depends on many factors; the type of structure, the natural period of vibration of the structure, and the quality of the construction. I want to dismiss the simplified conception that the closer you are to the fault, the more dangerous it is. That is not true. In fact, it can be much more dangerous for certain kinds of structures at greater distances from the fault.

This gets into the subject of acceptable risk. What is the degree of hazard that exists in terms of surface fault slip. No one would argue the consequences of even a few inches of displacement along a fault through a high density city center. Buildings could be shifted a few hundred feet one way and avoid the potential hazard area. But how often will the earthquake occur? It might occur only once every three hundred years or even a thousand years. This kind of research is advancing the state of knowledge and the state of the art right now. We need research to assess the risks and allow us to more adequately judge what risks are acceptable. Now most people would say a city center built over an active fault is an unacceptable risk. The risk there is too high, the potential there is too great. But we really do not have a good feel for that until we get an idea of how often it might occur. We would have to go through a whole process, in terms of quantifying the risks and then selecting what risks are acceptable, and finally making a value judgment. We are approaching a very exciting time from architectural and structural engineering points of view; a very exciting time in terms of developing ways to quantify the hazards, equating them to risk, and then trying to decide which risks society is willing to take. And of course, who makes that judgment? Does the person living in an apartment house on the fault make that judgment? Is it the residents or the government or building owners who are gaining revenue from the buildings who make the decisions in terms of assessing the acceptable risks.

Summing up the problems of surface faulting, we have faults that move in a horizontal direction, like the San Andreas Fault. We have geological evidence to show where the most hazardous locations are. When the fault finally slips, we can predict in what direction it is going to occur, how much it might be, how often it might occur, and the result. Of course the degree of hazard or risk is dependent upon what kinds of facilities are there or planned at that location. We have to know the kind of fault, the amount of displacement, and the type of displacement before we can really assess what fault zones we have to be concerned about. In other words, at San Andreas and Hayward Faults—the kinds of faults that predominate in the Bay area—the zone of surface rupture tends to be extremely narrow. In most cases, it is only a few tens of feet wide. It varies, of course, depending upon the geologic conditions and the amount of displacement, but generally the zone of disruption is extremely narrow.

There is another type of fault, a normal dip slip fault like the Wasatch Fault that runs through Salt Lake City. Since buildings may be located on either side of these faults, which is the safest side? Well, it depends. In this case, the buildings on most of the fault in the downthrown block would be heavily damaged, whereas the buildings on the upthrown block would come through without any trouble from surface faulting. They may be destroyed from shaking of the fault, but it is the orientation of the fault and the geometry; that is important to know. It might be safe on one side of the fault and very hazardous on the other side, unless you were several thousand feet away.

Now let's contrast that with even another type of fault--a thrust fault. The upthrown block can be the most highly displaced, the exact opposite of the last example. So one can not just categorically define a zone 50 feet away from any fault and be safe. It depends on the type of fault, the geometry involved, and the kind of displacement. Provided enough geological knowledge is available, certain estimates can be made because a record is often recorded in the younger geological materials that exist near fault traces.

In my opinion, damage from surface faulting has received too much past emphasis. It is not as important as shaking. It is, on the fault—there is no question about that—it is dominating and it controls everything. But in terms of total earthquake hazards, the total earthquake risks, it is really almost insignificant compared to the problems caused by shaking.

GROUND SHAKING

One of the most important, most difficult things to handle, from a design point of view, is the shaking problem. The basis for shaking is the size of the earthquake, the ground the building is located on, the ground motion, and the ability of the building to resist that motion. So the size of the earthquake is one important parameter; it is not the most important factor—but it does control a lot of other things. The duration of the earthquake is extremely important. You can have a potentially damaging earthquake, but if the duration and the cycles of shaking that occur are low enough, most buildings come through without any serious damage. But if you continue to excite a building to a limit of cycles, not too many survive very well. So duration is extremely important. The frequency of the motion is also extremely important in relation to the natural period of vibration of the building. The distance from the energy release and the intervening geologic and soil conditions effect the period and frequency of the motion at the time it comes out of the ground.

So it is a matter of trying to understand all these parameters and come up with a guess—that is the best we can do right now. Some of the guesses are pretty rough in terms of the dynamics of the motion, the frequency of the period, the duration, and the acceleration values that are the motion input to the base of the structure. You can have two sites that are very close together and have very dramatic differences in those parameters. And, depending upon the design of the building, it can perform differently. It is important to understand the size of the earthquake, where the energy could be released, the orientation of the building with respect to the site, and how the motions will be modified as they are transmitted through the earth's crust, and finally up to the building. The detailed geologic and soil conditions under each building can have a dramatic impact, so it is important in the design of critical, highrise, or important structures to get this information if it is available. Then quite reliably, I think, one can predict, within a general range, what these parameters will be, so that they can be taken into account.

GROUND FAILURE

The next topic is ground failure. Ground failure is directly related to shaking. It is a secondary effect of the shaking that causes the soil conditions or geologic conditions at a given site to lose their strength in one form or another. Spectacular examples of liquifaction, landslides, and differential settlement have been seen in past earthquakes. The important thing to understand is the level of shaking that might be imposed upon a given site, the detailed geologic and soil conditions that exist at that location, and their ability to hold their strength under the given shaking conditions. We do not presently know as much as we would like about ground failure. A lot of progress, particularly since the Alaskan earthquake in 1964, has been made; but there is ground yet to be broken before the data can be made quantifiable. Ground failure is one of the most potentially widespread forms of damage that has yet to be recognized, and not only in areas like California. This was the mode of failure in the Missouri area, the New Madrid quakes in 1811 and 1812 and other parts of the United States, particularly in the Midwest and on the East Coast. In those historic earthquakes, the degree of ground failure would far outweigh the shaking problem in terms of potential disasters. The frequency of occurrence in some of these other areas, of course, is much less, so one has to balance the potential of occurrence with how often it might occur and how bad it might be.

An example of ground failure is landslides. No matter how well the structure is designed to resist the shaking effects, if it is on a potential slip plain of the landslide one would have a hard time designing to accommodate that. There are ways of handling it—either moving like the fault moves, moving the site, or, in case of land-sliding, correcting the situation. I have worked on projects where it was deemed that the property investment was great enough to completely correct the landslide problem in terms of complete excavation, recompacting, complete drainage, and to build the site back to a stable condition. It is extremely expensive but it can be done.

Another example is the response of different materials; the interplay of the shaking and the soil conditions in terms of ground failure. For instance, liquifaction is the loss of strength due to the shaking. The shaking causes the sand, which derives its strength from the geophysical friction between the grains, to become saturated and turn into a quicksand. The sheer strength is transferred to the area between the sand grains and, since that is water and water has no sheer strength, it turns to liquid.

Solving the problem rests with identifying the potential for liquifaction and assessing the ground motion that might occur. What are the possible solutions? You either avoid it, or if the investment is large, it can be economical to correct the situation, through deep foundations or, if the ground is shallow enough, the use of excavating the material and re-compacting it. The most important thing is to recognize that the potential exists; and it is the job of the geologist and soils mechanic to do that prior to construction.

TSUNAMI EFFECTS

There are many examples of destructive tsunamis, or earthquake-generated ocean waves. Earthquake waves can be generated that travel with extremely high velocity (on the order of 600 miles per hour) on the open ocean. Since they do not build up, their amplitude on the open sea is very small and often not even felt by ships riding over them. But when these waves reach the shallow part of the ocean, because of the relationship between the configuration of the bottom floor, the geometry of the shoreline, and the direction of propagation of the wave, the wave can become really destructive. There is great potential for destruction by tsunami action in areas where typical shoreline development has occurred. These large waves have tremendous power, and often reach shore on the order of every few minutes to every few hours causing a great deal of destruction.

It is not tsunamis generated locally but the distant ones that are often most destructive. Earthquakes occurring on one side of the Pacific can affect South America and North America, as the Alaska earthquake affected Crescent City, California. The dangerous places are where the configuration of the coast line and direction of the propagation of the waves is such that waves can build to tremendous heights.

Again, one has to take into account the frequency of occurrence and what the hazards and excessive risks are. We are fortunate that when earthquakes occur we have tsunami warning. When the waves are generated we know enough about this phenomenon and the speed at which they travel that the warning goes out to all the low areas and susceptible places can be evacuated. I want to leave with you the thought that in coastal developments, particularly along the Pacific Coast and in places along the Atlantic Coast and in the Caribbean where there is the potential, the possibility for tsunumi sometimes is completely ignored in building codes.

CONCLUSION

In summary I would like to emphasize that while there have been many earthquakes in California, Nevada, and southern Utah, there have also been quite a few on the East Coast, particularly in the New England area and at the border of Tennessee, Arkansas, and Missouri. This border was the location of the 1886 earthquake where there was widespread areas of liquifaction. Thirty or forty miles apparently turned to liquid in that area. We have to look at the frequency of occurrence in terms of what it would do today. I would anticipate that the degree of hazard from an earthquake in this area is much greater than from earthquakes on the West Coast. The frequency of occurrence, of course, has to be taken into account in terms of assessing what the real risk is. We do not know what that is, but we are working on it. Of course the density of population is more significant for most parts of the Midwest and the East compared to many parts of the West.

It is important to know that no place in the U.S. is free from the potential for earthquakes and often, except for extremely critical facilities like nuclear reactors, we do not pay any attention to the earthquake potential in the eastern part of the United States.

I have discussed some of the elements that have to do with the information that the geotechnical engineers, the geologists, and seismologists provide to the architect and structural engineer. There are many steps through the process to understand the seismicity of the area and the seismic geology. This includes the location of active faults as well as the hazards from ground failure and ground shaking. The geologist has to have certain information, like the motion that could be generated during the earthquake, and soil response, before he can select the design earthquake for an individual structure.

We have come a long way in the last ten to fifteen years, but there is a lot of ground yet to be covered. We can, even in quantitative terms and certainly in a lot of qualitative terms, assess what the effects of a given earthquake would be. There is a lot of work yet to be done to be able to do this assessing accurately. A great deal can be done in regards to building design, provided that this geologic input is used in the early stages of building design. Architects are most often in the prime place to use the geologic input from a seismic standpoint to avoid problems usually not recognized in the early design phases. If the problem is serious enough, it is possible to avoid a hazardous site or to plan around it to minimize the effects by taking these hazards into account in the design.

I would like to end with this one thought; with an interdisciplinary approach requiring a geologist, seismologist, structural engineer, architect and planner, and the support of the public and elected officials, it is possible, theoretically, to have, from a large earthquake, rather than a spectacular disaster nothing more than an exciting experience.

LAND USE PLANNING FOR SEISMIC SAFETY

George G. Mader, AIP

CONTENTS

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LAND USE PLANNING FOR SEISMIC SAFETY

INTRODUCTION

I interpret my charge at this institute to cover, in broad terms, the role of land use planning in increasing seismic safety. To fulfill this assignment, I will review the state-of-the-art in this field and in the process provide a number of specific examples. It is only in recent years that planners have begun to involve seismic factors in land use planning to any significant extent. However, while our experience is limited, there are a number of promising approaches to dealing with the seismic problems in land use planning.

Before diving into the essence of the subject, it is appropriate to provide some orientation. I would, therefore, like briefly to discuss four topics. 1) professions involved in furthering seismic safety, 2) the roles of governmental levels in seismic safety, 3) the land use planning process, and 4) other approaches to seismic safety.

Because seismic safety planning involves an understanding of the triggering force of earthquakes and the manner in which this force is translated through bedrock and soils to buildings, a range of professionals is required in order to adequately deal with the subject. The planner and the architect are but two professions within the field. However, each professional must have an appreciation for the roles of the others in order to be effective in their own areas of specialization. Also, seismic safety often requires a close working relationship between certain members of this group, depending on the nature of the problem. Professions involved include at least the following: seismology, geology, engineering geology, soils engineering, civil engineering, structural engineering, architecture, planning, and building inspection. The planner is usually in most contact with the engineering geologist and soils engineer as they describe the effect of earthquakes and the civil engineer and structural engineer as they describe how an earthquake will affect the works of man. The planner is thus often in the position of weighing these two inputs in recommending land uses.

Seismic safety also involves multiple levels of government. By and large most land use planning takes place at the local level. It is here that most specific decisions are made that will affect seismic safety. Other levels of government, however, may play strong roles in directing the seismic safety actions at the local level. The Federal

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This paper draws extensively from a report (in process) of William Spangle & Associates under contract with HUD and USGS entitled Seismic Safety and Land-use Planning, by M.L. Blair and W.E. Spangle and a paper "Land Use Planning Tools to Reduce Earthquake Damage" by George Mader, prepared for the American Institute of Planners National Workshop 'Earthquake Disaster Mitigation as a Principle of Land Use Planning,' held in San Diego, California, November 7-10, 1976.

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level may, for instance, through Federal insurance regulations or basic research and dissemination of information limit actions at the local level and foster better seismic safety planning. States can also play a strong role through the provision of information and especially through state legislation mandating local seismic safety actions. I will discuss the state role later in several examples. Of course, each level of government has the responsibility of including seismic safety in its own governmental projects such as dams and freeways.

Now let us focus for a moment on the land use process as it typically operates at the local level. Usually, the land use planning process has the general plan as its core. This is a long-range policy guide for the future development of a planning area, looking ahead on the order of 10 to 30 years. This plan should be comprehensive in that it should consider all types of land use and circulation facilities. It should also be general in nature because of the obvious impracticalities of planning in detail for that time period. Also, it must be capable of change from time to time as conditions change. It should, however, present the best thoughts of a community at any one point in time of the type of future envisioned. It may govern some development that takes place in the near term, and may affect other development that will take place far in the future.

The general plan is, of course, useless unless there are tools for its implementation. In implementation, the planner usually relies heavily on zoning ordinances, subdivision regulations, to some extent on grading and building codes, and on capital improvement programs. All of these implementation devices are primarily short-range devices, that is, they affect the immediate use and alteration of land, and they should be based on the general plan. In California, State law now requires that all cities and counties have officially adopted general plans and that zoning ordinances be consistent with general plans. Because of these requirements, the general plan has taken on more importance in this State.

In the planning process I have described, the planner normally works with generalized information in formulating the general plan. Then, as the geographic area of concern narrows to a part of the community in implementation stages, first zoning, then perhaps subdivision and finally grading and construction, increasingly detailed information is developed by the community or those proposing development. Thus, the planner characteristically moves from the general to the specific in his work.

In going about preparing a general plan what kinds of information does a planner need to consider? The answer is all factors that can have a significant bearing on the plan. He often considers these factors under the broad headings of economic, social, political and physical. A single land use proposal in a general plan may result from considering a combination of these factors and in effect represents a compromise. In other instances, one factor may so outweigh the others that it in effect dictates the proposal. Now, seismic hazards are but one category under the broad heading of physical concerns. The insignificance of seismic matters and, in fact, basic geologic concerns in planners' work in the past is reflected by the almost complete lack of geologic material in planning texts and courses.

I hope that you now appreciate, if you didn't already, that the planner starts his planning work for an area usually by preparing a general plan, with limited data, a requirement to consider a wide variety of factors that affect plan proposals, and the knowledge that the general plan sets up important distinctions in land use that tend to be perpetuated in the implementation process. Also, it should be clear that seismic safety matters are but one of the factors that must be considered in making land use proposals. To lend some additional realism to this picture, remember that the planner is confronted with substantially different problems in raw land areas, areas undergoing normal change as new buildings replace old ones, and in redevelopment areas where deteriorated or blighted buildings must be replaced.

This description of the planning process and its relationship to geologic data requirements is illustrated in Figure 1. Note that broad geologic data is needed early in the planning process and that more detailed data is needed in later stages of the process.

Of course, land use planning is but one part of a spectrum of activities aimed at coping with the effects of earthquakes. Seismic safety is not simply achieved by avoiding putting structures in areas of potential seismic hazard. Safety can be achieved by many other approaches. The planner must be aware of these other methods and deal with the professionals involved to better define his scope of input. Let's consider a few of these other approaches:

1. Structural Engineering - Structures can be designed to withstand tremendous shaking without failure and to withstand permanent ground distortion without collapse, although costs may be high. Thus, many potentially hazardous areas can be built upon if proper structural engineering is used. The question is, "Is the value of the location sufficient to warrant the construction cost or should an alternate site be chosen?" Also, there are sites where hazards are so severe that structural solutions are not technically possible.

2. Redundancy - A facility likely to fail in an earthquake may be acceptable, if the system has redundancy built in. For example, a water line that crosses a fault may be acceptable if there is another supply source that can serve the affected area until repairs can be made.

3. Insurance - While we might like to plan for complete life and structural safety, it may be that as long as life safety is adequately taken care of, a calculated degree of structural damage can be tolerated if adequate insurance is available to cover the cost.

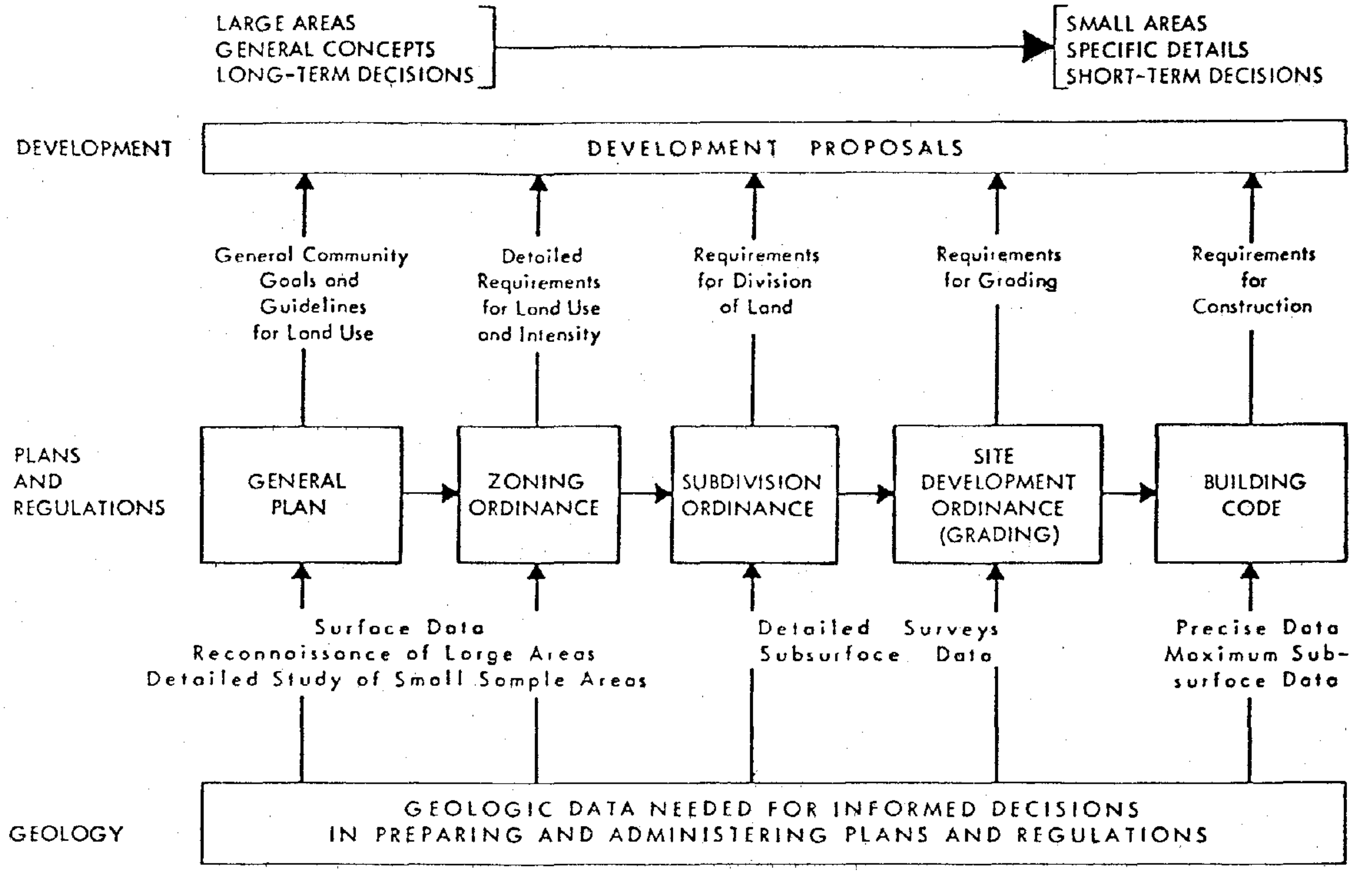

Figure 1 - The planning-regulation-development process

4. Warnings - It is common to use warning systems in areas subject to tsunamis (earthquake induced tidal waves) to warn occupants of low lying coastal areas thus giving them time to move to higher ground for life safety. This approach may in time be extended to other earthquake induced phenomena.

These are but a few examples of methods other than land use planning which can be employed to lessen the impact of earthquakes. Now, let us consider the role of land use plans in seismic safety.

LAND USE PLANS

The first important step is to bring seismic concerns into the variety of plans that can help increase seismic safety. Thus, typical general plans are considered here as well as redevelopment plans and post-earthquake plans. The several levels of government mentioned above should also be considered from the Federal to the local level. This paper is not organized by governmental levels, however, so the reader will find references to different governmental levels throughout.

AN IDEALIZED LAND USE PLANNING APPROACH TO SEISMIC SAFETY

It is possible to describe a model for the preparation of a land use plan that properly takes seismic factors into account. No one to date, to my knowledge, has given full consideration to all factors I will mention. The model will provide context for the actual plan examples I will deal with shortly.

My model has three components: geologic evaluation, structural evaluation and establishment of acceptable risk levels. The geologic evaluation would include mapping and analysis of all seismic hazards including surface faulting, ground shaking, liquefaction, landslides, differential settlement, tsunami and seiche. Each hazard would be described by the earth scientist in terms suitable to a structural engineer. The structural evaluation would consist of an evaluation of the probability of failure of basic structural types for each of the composite hazards at all sites in the planning area, probably on a detailed grid system. A suitable range of occupancies would also be analyzed for each building type. The structural engineer would then provide probability or risk figures for structural damage and life loss for all major combinations of structures and occupancies for each grid cell. The third part of the model is the selection by the community of the risk levels they are willing to accept. Once these levels have been selected, a computer program would enumerate all acceptable structures and occupancies for each grid cell. This printout would be in effect a capability scoring and would be the seismic safety input for the preparation of the land use plan.

GENERAL PLANS

The final responsibility for seismic safety in most instances resides at the local governmental level. In California, the recent State requirement for seismic safety elements of general plans plus local responses to date provide considerable background on the state-of-the-art in this field.

California Seismic Safety Element Requirement

In California, all cities and counties are required to prepare and adopt a general plan which includes at least the following elements: land use, circulation, housing, conservation, open space, seismic safety, noise, scenic highways, and safety. California law further requires that zoning and subdivision of land be consistent with the adopted general plan.

The requirement for a seismic safety element was enacted in 1971 soon after the San Fernando earthquake in accord with a recommendation of the Joint Committee on Seismic Safety. Section 65302(f) of the Government Code requires in part:

> "A seismic safety element consisting of an identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting, to ground shaking, to ground failures, or to the effects of seismically induced waves such as tsunamis and seiches."

This legislation provides the basic framework in California for local government efforts to reduce seismic risk. By incorporating a seismic safety element in the general plan, State law requires, in effect, that cities and counties consider seismic hazards in formulating and implementing the general plan. The seismic safety element is strongly related to several other required plan elements. As stated in Guidelines prepared by the Council on Intergovernmental Relations:

> "The seismic safety element contributes information on the comparative safety of using lands for various purposes, types of structures, and occupanices. It provides primary policy inputs to the land use, housing, open space, circulation and safety elements."
>
> (Calif. Council on Intergovernmental Relations, 1973, p.IV-27)

A committee of the California Seismic Safety Commission recently completed a review of the effects of this legislation. The committee found that by early 1977, approximately eighty percent of the cities and counties had adopted seismic safety elements. Characteristically, the elements consist of a background report prepared by geologists or geologists and planners, plus a policy document intended to be included as a part of the adopted general plan. The quality of the elements has a wide range from those that brush the topic lightly to those that deal with the subject in great depth. It is clear, however, that the effects of the legislation have been felt state-wide and have led to local identification of seismic problems and formulation of policy, and are leading toward significant impacts on land use decisions. The newly adopted elements have not, however, been in effect for sufficient time to judge their real impact. The State has by means of this legislation told local government to take seismic safety into consideration in general plans. The State has not yet said it will judge the adequacy of the local response.

The State requirement has generated a variety of approaches to dealing with seismic safety. The variations result from a variety of differing local conditions such as budget, sophistication, political concern, staff capabilities, and geologic conditions. This variety can be seen as salutory because it has led to many different approaches in a field where no one claims to have the perfect approach. Experimentation is in order. Now, let's consider a few seismic safety elements which demonstrate some important different approaches. This review will cover only selected aspects of each element.

Santa Barbara County

The Santa Barbara County element illustrates the use of land capability analysis in seismic safety planning. Land capability studies are an important tool in land use planning and decisionmaking. In any area the existing natural features and processes present a range of constraints and opportunities for different uses of land. Land capability studies systematically record and formalize judgements concerning the physical features of the land with regard to particular categories of land uses. Such studies evaluate, for a specified land use, the relative physical merits of the lands in a study area. The natural features and processes considered usually include topography, hydrology, geology, soils, vegetation, and climate.

The Seismic Safety Element of Santa Barbara County uses techniques of land capability analysis to rank areas in terms of relative seismic or geologic hazard. The following hazards were evaluated: ground shaking, tsunami-seiche, liquefaction, slope stability, expansive soils, soil creep, compressible/collapsible soils, high groundwater. Surface rupture was considered separately because, as an essentially linear phenomenon, it is difficult to incorporate into a grid analysis.

Each 90-acre grid cell was rated 1 - 3 for each hazard based on the following system: 1= none to low hazard, 2= moderate hazard, 3= high hazard. A second number was used to indicate possible variability from the rating due to potential local variations, lack of basic data and subjective evaluations. Each hazard was then given a weight representing its importance relative to the other hazards. The weight was a judgement based on three considerations:

1. Consequences - i.e., loss of life or property damage; severe or moderate

2. Frequency of occurrence.
3. Difficulty of prevention or mitigation.

Weights:

Seismic severity (ground shaking)	18
Tsunami-seiches	19
Liquefaction	15
Slope stability	23
Expansive soils	7
Soil creep	4
Compressible/collapsible soils	11
High groundwater	3
	100 (lowest possible score assuming rating of 1 for all hazards)

The weighted rating was obtained by multiplying the weight by the rating. The sum of weighted ratings for each land unit is called the GPI (geological problem index). The range of weight ratings was 100 - 236 (300 maximum). No cell received a maximum rating because some problems are confined to flatland or hillside areas and no one cell had a high rating for all hazards. The GPI was assigned to categories as follows:

GPI range	Category	Severity
100 - 125	I	low
126 - 145	II	low-moderate
146 - 180	III	moderate
181 - 210	IV	moderate-severe
210 - up	V	severe

The GPI was calculated for each 90-acre grid cell county-wide and for each 5-acre grid cell in four urban study areas. Computer mapping of the five categories shows the relative severity of geologic hazards throughout the County and in the four urban areas (in greater detail).

Areas with the same GPI rating or in the same severity category may have a different variability number which can affect planning recommendations.

Based on the GPI, the following land use recommendations were included in the element:

1. Consider areas in Category V for natural areas, recreational or agricultural use, possible low density use.

2. Consider Category IV lands for low density use or non-development. Cost of safe development may be high.

Santa Clara County

The Santa Clara County Seismic Safety Plan illustrates an approach of developing within a general policy framework project review requirements and procedures. This is appropriate especially when detailed data on seismic hazards are not available. Generalized data can be used to develop an "early warning system" alerting planners and decisionmakers to potential problems. Such a system generally identifies areas where seismic, geologic or soils investigations may be required prior to approval of development proposals. Specific report requirements, procedures for evaluating reports and requiring hazard mitigation steps, and criteria for determining the acceptability of proposed projects can be developed to incorporate seismic safety concerns in the decisionmaking process.

Project review can be very effective by assuring that seismic risk is considered in site selection, structural design, and occupancy of major development proposals. In general, the burden of collecting data is on the potential developer. However, the public agency must have sufficient information and geologic expertise available to evaluate geologic/seismic reports submitted with development proposals.

The Santa Clara County Seismic Safety Plan (1975) contains a thorough description of the seismic and geologic hazards in the County and general policies to mitigate or avert undue seismic risk in existing or future development. The essence of the plan, however, is contained in the recommendations for geotechnical site investigations:

> "In order to maximize public safety and minimize seismic hazards, additional local geotechnical studies should be performed prior to further development in many areas of the County. These studies should consider the data in this report as general background and regional material and should determine the extent of particular seismic hazards on each site in relation to the specific intended use.
>
> These geotechnical investigations should be multidisciplinary, including component studies of seismology, engineering geology, planning, hydrology, architecture, design engineering, structural engineering, and soil engineering. These interrelated components should be considered so that all pertinent factors are considered.
>
> To review and approve these geotechnical investigations, it is recommended that the County should develop an adequately trained and funded staff team including the various disciplines mentioned above." (Santa Clara County, 1975, p. 19-20)

To decide when a geologic or geotechnical investigation should be required, the County uses a Relative Seismic Stability Map prepared by the California Division of Mines and Geology at a scale of 1" = 1 mile. The map includes three categories of lands:

1. where geologic investigation is normally required
2. where geologic investigation may be required
3. where geologic investigation is not normally required.

The original map is incorporated, by reference, in a County ordinance setting forth soil and geologic report requirements (Santa Clara County Ordinance No. NS-1203.31, December 1974). Soil and geologic reports may be required with applications for subdivisions, building site review, grading permits, and building permits.

Soil reports are to be prepared by a civil engineer registered by the State and geologic reports by a State registered engineering geologist. The County staff includes an engineering geologist, and other experts competent to evaluate the reports and proposed mitigating measures.

Santa Clara County Baylands Study

The Santa Clara County Baylands Plan has as an important part, considerable focus on judging risk. A key task in developing an effective planning response to seismic hazards is evaluating seismic risk and formulating public policy related to that risk. In so doing, it is important to distinguish between hazard and risk. A seismic hazard is an effect of an earthquake such as surface faulting, ground shaking, tsunamis, liquefaction, landsliding and other forms of ground failure. Seismic risk is the exposure of individuals and structures to potential injury or damage from seismic hazards.

The distinction between hazard and risk is important in seismic safety planning. The presence of an active fault is clearly a hazard; however, the degree of risk depends on the location, type of construction and occupancy of structures with respect to the fault. Given present knowledge of seismic phenomena, little can be done to modify the hazard, i.e., control tectonic processes, but much can be done to control risk or exposure to seismic hazards. This is the focus of seismic safety planning. This paper is too brief to allow a full discussion of risk analysis in seismic safety planning; however, the example drawn from Santa Clara County is summarized.

The Santa Clara County Baylands Plan (Santa Clara County, 1972) covers an area subject to liquefaction as well as other forms of seismic and non-seismic ground failure. Consultants' studies of geologic and structural engineering problems were used to identify the natural hazards of the planning area and to describe their implications for specific land uses. The resulting report divided the planning area into risk zones based on potential for settlement and ground failure under both seismic and non-seismic conditions. The assignment of risk categories to specific areas was based on the professional judgement of geologists and structural engineers in cooperation with planners. Table 1 lists the risk zones and the nature of the hazard in each. Figure 2 is a map of the risk zones. Table 2 relates land and building uses to the risk zones.

The plan adopts these uses with the stipulation that any developer in the Baylands provide data from test boring and sample testing in depth to demonstrate that a proposed development site is not a higher risk zone than shown. Establishing an Advisory Review Board was recommended to advise public agencies on the adequacy of engineering investigations, design and construction methods in the Baylands.

City of San Jose

The recently adopted General Plan 1975 of the City of San Jose is one of the first efforts to consider seismic risk as an integral part of a comprehensive plan. The land use pattern of San Jose is a classic example of urban sprawl resulting from very rapid development in the post-war period. An aggressive annexation policy and growth oriented political climate led to more than a fivefold increase in city population from 1950 to 1975--from just under 100,000 to 547,500.

The San Jose General Plan 1975 is a blueprint for managing future growth to reflect the City's ability to extend urban services, avoid development of unsuitable lands, and achieve a more efficient urban form and a better balance of land uses.

The plan contains specific policies related to lands considered unsuitable for urban development. Based on a goal of striving to minimize risk from natural hazards, the plan contains the following general policies:

> "1. The City shall not permit urban development in those areas where such development would constitute a significant potential danger to the health, safety, and welfare of the residents.
>
> "2. Low levels of 'acceptable exposure to risk' shall be established for land uses and structures in which failure would be catastrophic, which are required during emergencies, or which involve involuntary or high human occupancy.
>
> "3. Risks from natural hazards shall be reduced as much as possible in areas where human activity is necessary or already exists, and where the natural and man-made environment can be safely integrated.

Table 1
RISK ZONES FOR SETTLEMENT AND GROUND FAILURE
(ESTABLISHED BY SUBSURFACE CONDITIONS IN THE BAYLANDS OF SANTA CLARA COUNTY)

RISK ZONE	SURFACE EFFECT	SUBSURFACE CAUSE
A	LITTLE RISK OF SETTLEMENT OR GROUND FAILURE	
B_{DL}	SIGNIFICANT SETTLEMENT	LIQUEFACTION OF CONFINED GRANULAR LAYER IN ALLUVIUM (SEISMIC LOADING)
C_{S}	MODERATE TO SUBSTANTIAL SETTLEMENT AND/OR DIFFERENTIAL SETTLEMENT	CONSOLIDATION OF BAY MUD OR SOFT CLAY (STATIC LOADING)
D_{D}	SUBSTANTIAL SETTLEMENT AND/OR DIFFERENTIAL SETTLEMENT	CONSOLIDATION OF UNCONTROLLED DUMP FILL OR SANITARY LAND FILL (STATIC LOADING)
D_{SL}	FAILURE OF GROUND SURFACE	LIQUEFACTION OF GRANULAR SURFACE LAYER (SEISMIC LOADING)
D_{LS}	FAILURE OF GROUND SURFACE	LATERAL SPREADING TOWARD FREE FACE (SEISMIC LOADING)

Adopted from: Woodward-Clyde & Assoc. and others, 1970, Part II, p. 10

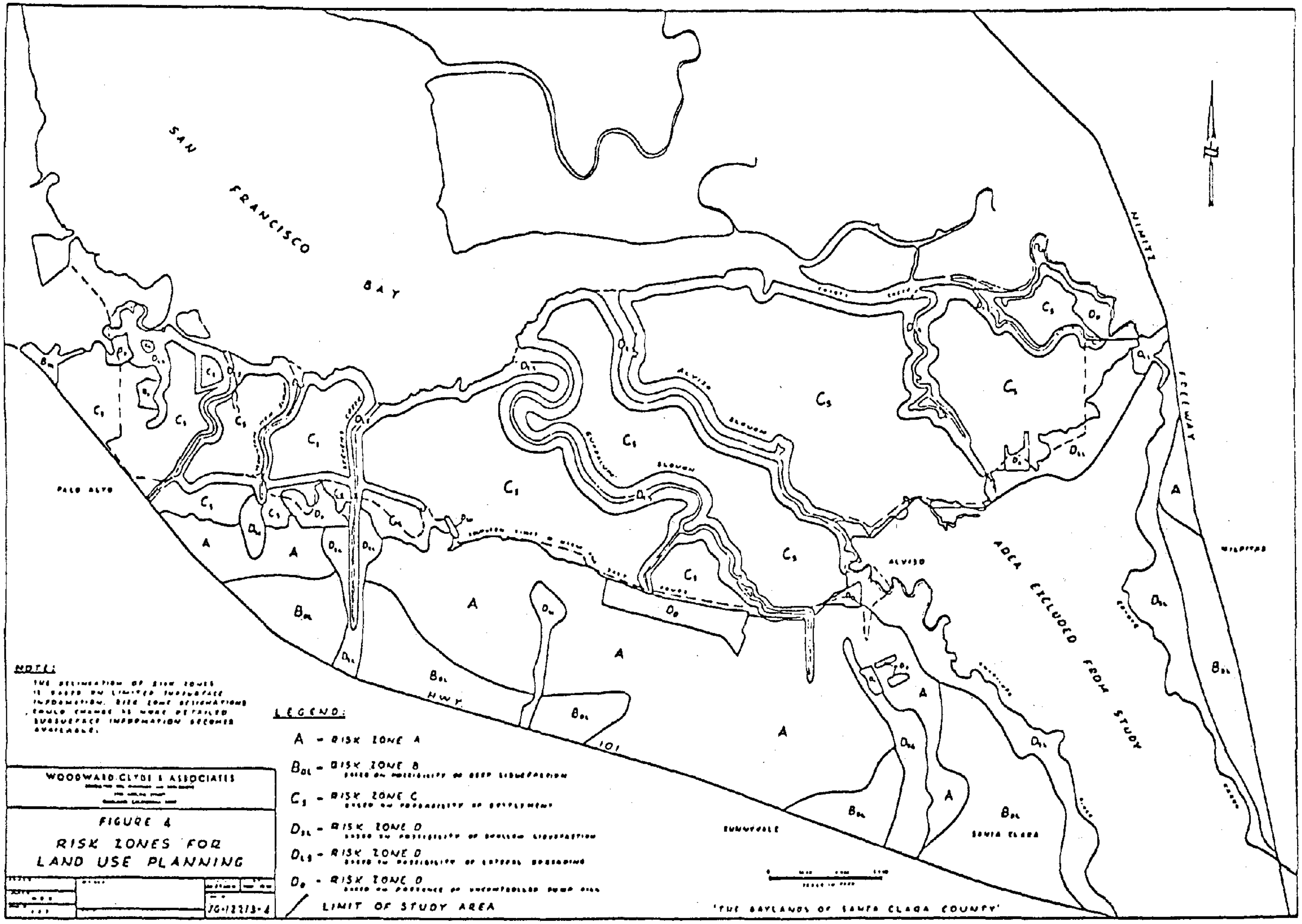

Figure 2. Risk zones for land-use planning, Santa Clara County Baylands. (Woodward-Clyde and others, 1970, part II, fig. 4.)

Table 2

LAND AND BUILDING USES FOR VARIOUS RISK ZONES

Land And Building Uses	RISK ZONES A	B	C	D
GROUP A BUILDINGS				
Hospitals and Nursing Homes	X			
Auditoriums and Theatres	X			
Schools	X			
Transportation and Airport	X			
Public and Private Office	X			
Major Utility	X			
Other Building Uses	X			
GROUP B BUILDINGS				
Residential-multiple units	X	X		
Residential- 1 and 2 family	X	X		
Small Commercial	X	X		
Small Public	X	X		
Small Schools - one story	X	X		
Utilities	X	X		
GROUP C BUILDINGS				
"Industrial Park" Commercial	X	X	X	
Light and Heavy Industry	X	X	X	
Small Public, if mandatory	X	X	X	
Airport Maintenance	X	X	X	
GROUP D BUILDINGS				
Water-oriented Industry	X	X	X	
Wharves and Docks	X	X	X	
Warehouses	X	X	X	
GROUP D OPEN SPACE				
Agriculture, marinas, public and private open spaces, marshlands and saltponds, and small appurtenant buildings	X	X	X	X

(adopted from Santa Clara County, 1972, p. 22)

"4. Preventative measures for known natural hazards shall be taken simultaneously with new development.

"5. Site specific information on natural hazards shall be required for proposed new development and where identified hazards preclude safe human interaction, development shall yield to natural processes.

"6. Provision shall be made for the continuation of essential public services during natural catastrophes.

"7. The City shall promote an awareness and caution among San Jose residents regarding possible natural hazards including soils conditions, earthquakes, flooding, and fire hazards."
(San Jose, 1975, p. 12)

Goals and policies pertaining to seismic safety include:

"GOALS:

"1. Minimize the risk to life and property from seismic activity including provision for structural resistance to

"2. Require that all buildings be able to withstand groundshaking from a minor earthquake without damage, a moderate earthquake without structural damage, and a major earthquake without collapse.

"POLICIES:

"1. The City shall seek to rehabilitate or eliminate structures expected to collapse or fail in a major earthquake; and equitable regulations shall be established which will accomplish this and/or mitigate risks without creating undue hardship or relocation policy problems.

"2. The City shall not approve high risk land uses in earthquake-prone areas; except that such uses may be approved with mitigating measures when alternative sites are not available.

"3. Construction shall be restricted in areas principally adjacent to and within creek channels, where seismic activity can produce liquefaction when the location of such facilities and utilities on unstable soils cannot be avoided, effective mitigating measures shall be taken. Such facilities and utilities shall, in no event, be located in areas of extreme soil hazard.

"4. The City shall continue to require geotechnical studies for development proposals; studies which determine the actual extent of seismic or geologic hazards, optimum location for structures, the advisability of special structural requirements, and the feasibility and desirability of a proposed facility in the particular location.

"5. Standards shall be developed to insure that vital public utilities, communication and transportation facilities are built and located so that they have maximum potential to remain functional during and after an earthquake.

"6. Land uses in close proximity to water retention levees or dams with moderate or high potential for seismic failure shall be carefully regulated.

"7. Encouragement shall be given for appropriate regional, state, and federal agencies to study the seismic resistance of area dams.

"8. The City shall require detailed dynamic ground motion analysis and suitable structural design methods for all structures with a low level of acceptable exposure to risk.

"9. The City shall continue to follow requirements of the Alquist-Priolo Hazard Zones Act and impose additional investigative requirements on all development in areas defined by the Act and in addition, shall follow the predevelopment recommendations in the City's Geotechnical Report.

"10. The City shall continue updating, as necessary, the San Jose Building Code to incorporate the most recent edition of the Uniform Building Code."
(San Jose, 1975, p. 12)

These policies apply to areas designated as hazardous on maps which are part of the Geotechnical Report prepared by Cooper-Clark & Associates (1974) as background for the Seismic Safety Element. A generalized natural hazards map is incorporated in the General Plan 1975.

The importance of avoiding development of hazardous areas is reflected in the plan's land use diagram. This diagram shows the area underlain by Bay mud as open space, agriculture and light industrial. Areas adjacent to major creeks which may be subject to liquefaction are shown as linear parks and open space. Hillside areas to the northeast and southwest of the valley floor are designated for non-urban uses. In these areas, slope failure and surface rupture during an earthquake are major potential hazards.

City of San Francisco

A particularly difficult and costly problem is the abatement of existing structural hazards. In the San Francisco plan, damage from an earthquake similar to the 1906 earthquake was estimated from data on the age, use, construction type, number of stories and floor area of existing structures. Geologic conditions affecting ground motion were considered. The damage potential of each block was classified as severe, heavy, moderate or slight. In addition, an investigation was made of pre-Code, Type C buildings. Pre-Code buildings were constructed before 1948 when comprehensive lateral force requirements, specifically considering seismic forces, were incorporated into the San Francisco building code. Type C buildings have masonry or concrete exterior bearing walls with wood floors and roofs. Maps showing density of pre-Code, Type C residential units and non-residential structures by Census Tract were prepared. Over 1, 400 residential buildings with nearly 35,000 living units and 2,800 non-residential buildings were identified as pre-Code, Type C contruction. At 1974 construction costs, replacing these buildings would cost over one billion dollars (San Francisco, 1974, p. 20).

Objectives and policies to abate structural hazards are related to areas where damage levels are expected to be severe, pre-Code, Type C structures which are particularly subject to damage from earthquake effects, and Special Geologic Study Areas which have potential for ground failure or flooding. Priority is assigned to "(1) areas with high concentrations of potentially hazardous pre-Code, Type C buildings; (2) areas with high population densities, and (3) those structures for which there is a critical community need." (San Francisco, 1974, p.42).

Abatement of structural hazards in San Francisco can be in conflict with preserving the visual and architectural character of the city. Although San Francisco adopted an ordinance in 1969 requiring removal or strengthening of unsafe parapets and building appendages, little has been done to enforce the ordinance, in part because of its possible effects on the visual character of San Francisco. The Community Safety Plan makes the following observations in recommending preservation of the architectural design character of buildings when abating structural hazards:

> "The abatement of hazards to life safety will affect, primarily, the older structures in the city. Often the hazards presented by the structures are from those architectural design elements -- parapets,

cornices, and other ornamentation -- that give each their own special character. In cases where remedial work is required to abate hazards from structures important to the character of San Francisco, every effort should be made by the owner and the city to assure the preservation of the architectural design of the structure. This should be accomplished through reinforcing, replacing or redesigning in similar architectural style, building elements which present a life safety hazard."
(San Francisco, 1974, p. 45).

REDEVELOPMENT PLANS

In developed areas where extensive damage from future earthquakes can be anticipated in some detail, remedial measures should be taken. In some instances, the enforcement of hazardous building ordinances may be sufficient to bring risk to an acceptable level. In other instances a drastic change in land use may be warrented. In effect, such areas might be considered blighted by a highly certain seismic event and potential related damage. Earth scientists and structural engineers are not yet able to predict accurately building failures from all types of hazards; however, there is at least one type of hazard that could warrant such drastic treatment at this time--active earthquake faults.

The City of Hayward in the San Francisco Bay Area is faced with such a problem. The core of the city is astride the Hayward Fault along which fault creep is actively taking place. The city has identified the location of the fault traces (Hayward Earthquake Study (1972)) and subsequently studies the traces in greater detail. In a separate effort the city prepared a redevelopment plan for the old downtown core area which called for economic revitalization and expanded parking facilities. In yet another action, the State of California, through the Alquist-Priolo Special Studies Zones Act (described elsewhere in this paper) prohibited new structures for human occupancy astride named active faults and required special studies within defined zones. One such zone covers the core area of Hayward. The net result of these three items may well be that redevelopment efforts in Hayward will result in gradually removing buildings astride the fault and replacing them with parking facilties. Whether or not this is a successful effort in reducing seismic hazards, the example illustrates the potential usefulness of a redevelopment project prior to an earthquake that takes seismic factors into consideration.

POST-EARTHQUAKE PLANS

The problems of achieving proper post-earthquake land use planning are difficult to solve and the record in this country following recent earthquakes is not enviable. The problems stem from many factors, but looming large is the intense need to restore a city to a functioning condition so that people can resume their normal living patterns and the economy can again function properly. It has been pointed out by a planner involved in the post-earthquake rebuilding efforts in Alaska (Selkregg, 1971) that there need to be two phases of planning following an earthquake. The first phase addresses the short term needs, that is those actions necessary to restore the city to a functioning condition. Then, when the city is somewhat stabilized, the second phase of carefully establishing the long term reconstruction plans can begin.

Alaska

It has been pointed out (Selkregg, 1971) that the communities in Alaska affected by the Alaskan earthquake of 1964 did not, prior to the event, have plans that addressed the probable effects of an earthquake. Following the quake, nationally known consultant firms were hired to assist the local planners in planning. There was a strong desire to redesign parts of affected cities so as to avoid rebuilding for concentrations of people and buildings in areas where hazards were high. In time, however, the pressure to rebuild much as the cities had existed prior to the earthquake overcome many of the good resolves. A notable exception was the port city of Valdez. Here the heavy destruction, degree of hazard and importance as a port, caused the Federal government to relocate the entire city of 500 persons to a safer location.

City of Santa Rosa

The City of Santa Rosa in the San Francisco Bay Area was hit by an earthquake in 1969. While not a devasting earthquake, considerable damage was caused in the old downtown area. Many buildings were of old unreinforced masonry construction and not able to withstand significant shaking. Here, rather than immediately repairing or rebuilding partially destroyed buildings, the city took seismic factors into consideration in a redevelopment project for the central area. As a part of the redevelopment plan, buildings are being brought up to current codes or are being removed. In this manner, Santa Rosa is decreasing its earthquake vulnerability according to a well-thought-out-plan.

City of San Francisco

The San Francisco Community Safety Plan (San Francisco, 1974) addresses the issue of post-earthquake reconstruction with more depth than most California seismic safety elements by stressing the opportunities presented during reconstruction.

> "In a positive sense, post-earthquake reconstruction presents opportunities to affect actions and changes not possible prior to extensive damage; these opportunities would be related to transportation systems, land uses, building sizes and heights, location and connection of open space

> systems, and other factors. Properly directed reconstruction can provide the means for long needed improvements while correcting or eliminating past mistakes."
> (San Francisco, 1974, p. 31)

The following policies were adopted to guide reconstruction planning:

> "Policy 1: Maintain the sound and rational redevelopment of San Francisco, following a major disaster, by rebuilding in accordance with established comprehensive plan objectives and policies, appropriate city codes, and other community concerns and needs.
>
> "Policy 2: Adopt contingency legislation to provide for anticipated needs following a disaster and to reduce pressures for unnecessarily rapid reconstruction.
>
> "Policy 3: Create a reconstruction planning committee to insure that development following a major disaster takes place in a timely fashion according to established objectives and policies."
> (San Francisco, 1974, p. 38)

The proposed Reconstruction Planning Committee would have the following duties (San Francisco, 1974, p. 63-64):

1. Insuring that post-earthquake building code and design standards are as advanced in terms of seismic safety as possible.

2. Implementing objectives, policies and criteria of the Comprehensive Plan.

3. Recommending contingency legislation to be enacted now, but taking effect after an earthquake to authorize such actions as provision of temporary housing.

4. Determining priorities for allocating resources, particularly building materials.

5. Seeking joint agreements with lending institutions, insurance companies, and Federal disaster assistance agencies to require a valid building permit before money for new construction is released.

6. Developing an information booklet setting forth all requirements pertinent to reconstruction and sources of financial assistance.

REGULATIONS

It has been pointed out in the preceding part of this paper that plans for seismic safety lead in most instances to the need for effective implementation devices. There are a number of examples of such regulations in various cities and counties in California. Similar regulations exist elsewhere in the country although they characteristically address different types of hazards.

STATE DESIGNATED HAZARDS

It is becoming more common for states to designate areas of critical environmental concern. Thus, particular problems that occur statewide can be addressed and policy expressed.

In 1973, the California Office of Planning and Research published Environmental Goals and Policies setting forth recommended State actions to reduce environmental pollution and to protect environmental resources. The report describes environmental hazard areas, including geologic hazards, which threaten life and property, and which need to be carefully reviewed before decisions are made to change land use. The report recommends designation of areas of critical environmental or hazardous concern and formulation of guidelines.

> "to encourage orderly development and protection from natural calamaties while minimizing adverse impact upon people or resources...."
> (Calif. Office of Planning and Research, 1973, p. 3)

The plan further recommends that areas of high earthquake shaking, tsunamis, and fault displacement be designated as areas of "critical concern."

California does have one state-wide regulation which reinforces this policy statement, the Alquist-Priolo Special Studies Zones Act. This Act (Chapter 7.5, Division 2, Public Resources Code, 1972 as amended 1974 and 1975) provides that the State Geologist is to delineate special studies zones encompassing potentially and recently active fault traces in the State. The zones are ordinarily less than a quarter mile wide unless special considerations indicate the need for a wider zone. Once the Special Studies Zones maps have been officially issued by CDMG, local jurisdictions must require geologic reports prior to approval of any new real estate development or major additions to existing structures within the zones. Individual geologic reports are not required, however, for projects consisting of no more than one single-family, wood-frame home not exceeding two stories.

The California Division of Mines and Geology is responsible for establishing criteria and policies for content and review of the geologic reports and for revising the Special Studies Zones maps as new geologic information becomes available. Specific criteria include the prohibition of construction of structures for human occupancy across a fault trace and within 50 feet of a fault trace unless geologic investigation proves the absence of active branches of the fault.

ZONING ORIDNANCES

Zoning regulations can be used very effectively in dealing with seismic hazards. Examples of two zoning related tools developed by the Town of Portola Valley in the San Francisco Bay Area are described below:

Fault Zoning

A fault map prepared for Portola Valley provides the basis for the town's fault setback requirements adopted in 1973 (ordinance 1973-119) as part of the zoning ordinance (Danehy, 1972). The ordinance prohibits structures for human occupancy within 50 feet of a "known" fault trace. "Known" locations are based on surface expressions or subsurface explorations which fix the location of the trace. No use more intensive than a single-family, one-story wood-frame house or house of similar earthquake resistant design is permitted in the band from 50 feet to 125 feet on either side of a known fault trace.

Setback distances for an "inferred" fault trace are larger--no structures for human occupancy are permitted within 100 feet of the inferred location and only single-family homes are allowed for an additional 75 feet. "Inferred" locations are based on the presence of a limited number of surface or subsurface indications of a fault trace. The actual position of the "inferred" location is subject to wider error than the "known" location and therefore the width of potential risk band is increased. A property owner may contract for detailed geologic investigation to precisely locate an "inferred" trace. In such cases, the ordinance provides that the trace be reclassified as "known" and the setback requirement correspondingly reduced.

Outside the setback lines all proposals for development more intensive than single-family residences are reviewed by an engineering geologist employed by the Town to determine if the site may be subject to significant offset or ground warpage related to surface rupture.

Existing structures in the fault zone are not affected by the setback ordinance. Had the Town chosen to apply a zoning district to the fault zone rather than setback requirements, existing structures would have become non-confirming and subject to eventual removal depending on the zoning ordinance provisions covering non-conformity.

Landslide Zoning

Effective handling of slope stability problems in areas where development exists or is expected first require detailed mapping of failure-prone slopes. The approach of the Town of Portola Valley is one of the most comprehensive (Mader, 1974). Spurred by landsliding incidents in the wet winter of 1969, the town retained a geologist to develop information to guide land use decisions to avoid landslide hazards. Over several years a geologic map at a scale of 1 inch = 500 feet was produced and used as a basis for preparing a landslide potential map (officially titled the Land Movement Potential of Undisturbed Land Map) at the same scale. Provisions were added to the local zoning, subdivision and grading ordinances, requiring that geologic information be submitted for review and approval by the Town Geologist prior to development.

Even with the establishment of review procedures, it became evident that a consistent policy would be needed to relate the types of permissible land use to landslide potential. To assist in formulating such a policy, the town council appointed an eight-member geologic committee with expertise pertinent to landslide problems. Chaired by the Town Geologist, the committee included three geologists, two engineering geologists, a soils engineer, an attorney and a planner. The committee developed criteria relating land uses to stability categories shown on the landslide potential map as shown in Table 3. The geology map, landslide potential map and criteria were adopted by resolution by the town council to guide land development decisions. Even with mapping at a scale of 1 in. equals 500 ft., the town council felt that land use regulation through zoning or other specific restrictions was not warranted. Actual landslide potential of individual parcels within each mapped category may be variable. Site investigation may establish that a parcel is more or less stable than mapped. The resolution provides for incorporating new information from site investigations into the official map. The criteria adopted by the town are a matter of policy at this time; however, the town is moving toward incorporating these provisions into the zoning ordinance.

Portolo Valley's response to landslide problems emphasizes avoidance of hazardous areas. This is consistent with the town's existing and planned pattern of low-density residential development and policies for preserving the natural environment. In jurisdictions fostering urbanization or already intensively developed, landslide potential may be addressed with more emphasis on requiring special site and building design and engineering to mitigate the chances and effects of slope failure.

SUBDIVISION REGULATIONS

Even if geologic and seismic hazards have not been identified at an earlier stage in the planning-development process, much can be accomplished by a carefully conceived and carried out subdivision process. As a part of the subdivision process it is imperative that geologic hazards be identified and appraised. This requires legislative author-

Table 3

CRITERIA FOR PERMISSIBLE LAND USE IN PORTOLA VALLEY

	Land Stability Symbol	ROADS Public	ROADS Private	HOUSES (parcelacreage) 1/4-AC	HOUSES (parcelacreage)]-AC	HOUSES (parcelacreage) 3-AC	Utilities	Water Tanks
MOST STABLE	Sbr	Y	Y	Y	Y	Y	Y	Y
	Sun	Y	Y	Y	Y	Y	Y	Y
	Sex	[Y]	Y	[Y]	Y	Y	Y	[Y]
	Sls	[Y]	[Y]	[N]	[Y]	[Y]	[Y]	[N]
	Pls	[Y]	[Y]	[N]	[Y]	[Y]	[Y]	[N]
	Pmw	[N]	[N]	[N]	[N]	[N]	[N]	[N]
	Ms	[N]	[N]	N	N	N	N	N
	Pd	N	[N]	N	N	N	N	N
	Psc	N	N	N	N	N	N	N
	Md	N	N	N	N	N	N	N
LEAST STABLE	Pf	[Y]	[Y]	(Covered by zoning ordinance)			[N]	[N]

LEGEND:

- Y Yes(construction permitted)
- [Y] Normally permitted, given favorable geologic data and/or engineering solutions
- N No(construction not permitted)
- [N] Normally not permitted, unless geologic data and/or engineering solutions favorable

LAND STABILITY SYMBOLS: (as used on geologic hazards map)

- S Stable
- P Potential movement
- M Moving
- br bedrock within three feet of surface
- d deep landsliding
- ex expansive shale interbedded with sandstone
- f permanent ground displacement within 100 feet of active fault zone
- [s ancient landslide debris
- mw mass wasting on steep slopes, rockfalls and slumping
- s shallow landsliding or slumping
- sc movement along scarps of bedrock landslides
- un unconsolidated material on gentle slope

ity to require such information from subdividers, a professionally trained staff and a receptive decision-making body.

It is emphasized that the local reviewing jurisdiction must have expert review capabilities on its staff or available on a consulting basis. Experience has shown that the single most important step a jurisdiction can take to improve its planning and regulations with respect to geology, is to hire a trained geologist. Such a person can become a part of the ranks of government, educate staff and elected and appointed officials, and in the long run affect the attitude of government in this subject area.

In California, State law requires the preparation of soils reports for subdivisions. It also requires disapproval of a subdivision if the site is not physically suitable for the development. There is, however, no mandatory requirement for the preparation of geologic reports, although local jurisdictions can require such reports. Nontheless, there is now a rather good history of local governments doing an effective job by requiring and reviewing such information. The City of Los Angeles was an early leader in this field in the State.

A simple example from the Town of Portola Valley can be cited (Mader & Crowder, 1971). In this instance a subdivision was proposed on a 450 acre parcel. The town subdivision ordinance required a geologic study. The study requirements were stipulated by the Town Geologist (a consultant), the report was prepared by another geologist retained by the developer and then the study was reviewed by the Town Geologist. The report pointed out that the property was bisected by an active fault and, in addition, about one-third of the property was affected by active or potentially active landslides. With this information on hand, the developer designed a cluster subdivision in which the total number of permitted residential units was located on approximately one-half of the property and the remainder was devoted to permanent open space to be used by the residents of the subdivision.

BUILDING CODES

Although not the domain of the land use planner, building codes are a vital part of seismic safety programs. Structural engineers are in the process of improving building codes. Two areas in particular are worthy of mention. First, following the San Fernando Earthquake of 1971 it was discovered that the forces of earthquakes were significantly greater than previously believed. As a result, attention is being given to increasing the design standards so new buildings will better withstand future earthquakes. Second, it has been known for a long time that the shaking forces of a building are subjected to vary to a degree based on the soil and geologic conditions of the site. Hence, efforts are now underway to ensure that the actual building designs be required to take specific site conditions into consideration.

Another and very important aspect of building codes are the regulations for existing hazardous buildings. This is an extremely complex and politically controversial subject. While it stands to reason that old buildings in earthquake country that will probably not withstand a major earthquake should be either properly upgraded or torn down, carrying this concept out is very difficult. The pressures from landowners to not be forced to tear down or reinforce buildings are intense.

The cities of Long Beach and Los Angeles have had some experience in dealing with the problems of existing hazardous buildings. Long Beach has adopted special regulations in this field and has had significant success. Los Angeles is just now entering more energetically into this field and beginning to address hazardous buildings which are used as places of public assemblage. Most people agree, that the largest threat to life from a future earthquake in California will be from old unreinforced masonry buildings. Hence, this topic deserves a good deal of attention.

Included as Chapter 70 of the Uniform Building Code are provisions dealing with grading. Suffice it to say here, that grading just as well as structures would be reviewed from the geologic and seismic point of view.

OTHER APPROACHES

There are many other approaches to solving seismic safety problems of which planners should be aware. Some of these are briefly mentioned for background.

PROVISION OF INFORMATION

The supplying of geologic and seismic information to cities and counties is vital. This can often be handled, at least with respect to generalized data, by a central agency such as the state or the Federal government. We are all aware of the basic roles of state offices of geology and the USGS. Local agencies usually have to provide detailed data.

In California, the supplying of special dam inundation maps by the State is an example of data distribution by a central agency. Under the Alquist Dam Safety Act (Government Code, Section 8589-5, 1973), the Division of Water Resources consults with the Office of Emergency Services (OES) in identifying dams whose failure would threaten injury or loss of life. The owner of dams so identified must prepare a map showing the extent of potential flooding from dam failure at full reservoir capacity. These maps are then given to all potentially affected local governments. OES must review and approve all such maps which then serve as the basis for emergency evacuation plans drawn up by local governments with advice from the State.

SPECIAL GOVERNMENTAL AGENCIES

Special agencies with permit powers can effectively combine considerations of seismic concerns. A good example is the San Francisco Bay

Conservation and Development Commission (BCDC).

BCDC, created by the State Legislature, was authorized to prepare a comprehensive plan for San Francisco Bay and its shores and to control development within its area of jurisdiction. The adopted plan has legal status and serves as a guide in the review of projects. BCDC shares jurisdiction over land use decisions with the cities and counties which retain normal land use and building permit controls. However, with certain minor exceptions, a permit from BCDC is required for all projects within its area of jurisdiction. Thus it, in effect, holds veto power over any project proposal in conflict with the San Francisco Bay Plan.

The BCDC plan and its project review activities reflect a strong concern for seismic safety. The agency has an Engineering Criteria Review Board composed of geologists; structural, civil and soils engineers; and other professionals as recommended in the plan. The Board reviews and evaluates soils and geologic reports submitted by applicants for permits to fill. Significant improvement in the seismic engineering of fills and design of structures has resulted from the Board's insistence on a thorough evaluation of geologic hazards at a project site (San Francisco Bay Conservation and Development Commission, 1974, p. 8).

SPECIAL STUDY GROUPS

In California a special group was appointed by the Legislature in 1969 to investigate the problems of earthquakes in the State and make recommendations for legislation and programs. This Joint Committee on Seismic Safety studied the problem for four years. Its major recommendation was to establish a continuing body to investigate and watch over this field of interest. As a result, the Seismic Safety Commission was formed in 1975. In addition, the Joint Committee made a number of recommendations which are relevant to land use planning. That list is summarized on Table 4.

Table 4

SUMMARY OF RECOMMENDATIONS OF THE JOINT COMMITTEE ON SEISMIC SAFETY

SUBJECT AREA	RECOMMENDED ACTIONS
Land-Use Planning	Provide for effective State review of local seismic safety elements Require geologic and soils reports for subdivision and construction activity of substantial scope Permit seismic and geologic hazards to be considered "blighting" conditions making an area eligible for redevelopment funds Provide for preplanning of post-earthquake redevelopment Require evaluation of geologic and seismic hazards in environmental impact statements Employ land-use controls to reduce seismic hazards Discourage public investment in hazardous areas Provide purchasers of real estate with property reports disclosing seismic and geologic hazards
Building Construction	Upgrade engineering standards and building code provisions Assist local agencies in enforcing building code standards Develop programs to train building officials and other local personnel in seismic design Provide geologists, engineers, public safety officials and others with reasonable protection from liability
Abatement of Hazardous Buildings	Develop hazard abatement program concentrating on pre-1933 buildings Inventory potentially hazardous buildings
Critical and High Exposure Facilities	Enforce seismic safety measures in construction of schools, hospitals, and emergency facilities Review safety of high-rise structures and dams
Emergency Preparedness Measures	Ensure that local emergency plans are prepared and maintained as required Establish procedures for review and approval of such plans Conduct disaster exercises to test response Increase allocation to State Emergency Fund Require communities to prepare post-earthquake reconstruction plans
Research	Increase support of basic and applied research
Insurance	Require purchasers of residential buildings to carry earthquake insurance Explore with Federal Government the possibility of comprehensive disaster insurance

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SOILS AND EARTHQUAKES

Neville C. Donovan

CONTENTS

SOILS AND EARTHQUAKES

INTRODUCTION

The role played by the informed geotechnical engineer involved in earthquake engineering includes the coordination of information provided by geologists, geophysicists, seismologists and soils engineers. This information from different disciplines must be combined into directly useful information for two separate design purposes. First, the owners of the planned structure, the architects and the structural engineers must establish what is a reasonable level of ground motion for design (differences between this consideration and building codes are discussed later). Second, the chosen design level information must be converted into a form which can be directly used by the structural engineer.

The geotechnical engineer also has the role of avoiding hazardous seismic areas, or, if they cannot be avoided, of designing to mitigate the effects of these hazards. Basic information that must be considered in the preparation of information for the development of seismic design information include strong motion records, dynamic properties of soils, soil structure interaction and seismic risk evaluation. These topics together with some related aspects are covered in the following sections.

STRONG MOTION RECORDS

Most information regarding the engineering characteristics of ground motion is obtained from strong motion accelerograph and seismograph records. This information can be characterized in many ways. The more common quantities recorded are the peak value of acceleration, followed closely by velocity and displacement and the duration of the event. Peak values alone, however, are not able to characterize an entire event. They do not provide enough information. The response spectrum was devised to represent in a simple way how a structure might be affected by an earthquake. A response spectrum represents the distribution of energy among different frequencies as the ground is shaken by the earthquake. It is possible to show directly from observed response spectra that soft soil sites, where buildings are usually supported on piles, produce more severe shaking in tall buildings than on other sites. The converse is also true, that ground shaking may be less severe for a well designed short stiff building on the soft soil site. There are many other parameters relating to earthquakes that are frequently mentioned. These were described during the lecture series but are not covered in detail here. The principal terms include:

1) intensity
2) magnitude
3) seismic moment
4) duration

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5) response spectrum
6) attenuation
7) frequency characteristics
8) dispersion of waves

For a more detailed description of these terms a text such as Newmark and Rosenblueth's, Fundamentals of Earthquake Engineering (Prentice Hall, 1971), is recommended. While these are direct quantities or phenomenon there are other indirect problems. For example, what is the real significance of peak values and how has misunderstanding developed between geo-scientists and architectural engineers over apparently simple terms. We might consider the term acceleration and what it means to different people. Because the code lateral design forces are expressed as a fraction of the weight of a building this could be looked on as an acceleration value. The code, which unfortunately, and I believe not correctly, keeps getting bigger, presently gives a coefficient that would appear to be less than an equivalent 0.2g in most cases. A geophysicist looks at strong motion records and upon observing peak values of 0.5g and greater says, "see how the engineers are cheating, they are ignoring the real world and all their buildings will fall down". We as engineers recognize that high frequency motions may produce very high acceleration values. More important, however, geophysicists ignore the information engineers have gained from studies of earthquakes and building behavior. Buildings carefully designed with code coefficient values have performed well. As an example, look at the success record of school performance in California since passage of the Field Act.

The difference between code working stresses and real stresses, ductility requirements etc. all enter into this difference of numbers. What is necessary is the attempt to have engineers recognize and use the seismologists data and at the same time convince the seismologists that the values the engineers are using come from and are compatible with the seismological information.

The design acceleration value we recommend is a value by which a reasonable response spectra may be scaled for design purposes. It is not a maximum value but a mean peak value. This is also the reason why the scatter about the mean value is so important.

DYNAMIC PROPERTIES OF SOILS

The most significant factor affecting earthquake ground motions is perhaps the nonlinearity of soil properties. Failure to recognize this has led to occasional gross mininterpretation of data. For example, measurements of ground motions produced by Nevada nuclear testing events in the San Francisco Bay area show large amplification of peak motions by soft soils. These data have been used by some people to attempt to microzone the area and imply that the shaking due to strong ground motion will be many times larger of soft ground. There is evidence to support the change in the frequency content of the motion by site soil profiles but little to show increased intensity provided secondary effects such as liquefaction or landsliding have not occurred. The published reports showed an increased damage rate in the soft soil areas of San Francisco in 1906, but these should be reviewed carefully. Two factors exist to mitigate the evidence that the shaking was much more severe. Considerable liquefaction occurred in the landfill areas which both disturbed and undermined building foundations. At that time the significance of differential settlements was not recognized. The result of this was that many structures that failed were probably in a considerably weakened condition when the earthquake occurred. This is not intended to downgrade the importance of adequate site selection and evaluation but to show both the necessity of considering all aspects of reported situations and the need for interdisciplinary expertise. This area of seismic engineering must be emphasized here as many publications and papers do not make this distinction.

Dynamic soil properties can be measured by field or laboratory tests using different procedures for different levels of stress and strain. Both the shear modulus and damping ration are strain dependent. The liquefaction potential of granular soils can also be directly evaluated by laboratory testing or indirectly estimated by correlation of field tests with similar tests in areas where liquefaction is known to have occurred.

SEISMIC RISK EVALUATION

For design one needs to make a decision as to what level of risk should be taken. Requirements for public safety and life protection do not mean that a structure should stay completely operational during all foreseeable natural disasters. Seismic risk procedures provide a useful method for estimating seismic design criteria on the basis of "how much is enough". Four direct items must be considered in design for earthquakes. These are:

1) Where will an earthquake occur?
2) How big might the earthquake be?
3) When will the earthquake occur?
4) How often do earthquakes occur?

The first two items are often directly addressed by geologists. The answer to the third item is not yet possible and in many areas item 4 is completely ignored. The combination of all four items takes place in a seismic risk analysis. The geologic information is combined with seismological recurrence data and attenuation relationships to estimate mean recurrence intervals for different motion levels at the site of interest. Results are usually expressed as a probability of exceedance during a structural lifetime which can be used for choice of acceptable risk for design. The choice of an acceptable risk level is one that should be reached in meetings between the owners of a structure, the architects and the design engineers.

ESTIMATING GROUND MOTION CHARACTERISTICS FOR DESIGN

The design of structures is usually based on two levels of motion. The lower level event is one which has a good chance of being exceeded once or more during the life of the structure. The structure is usually designed to remain elastic during this event. The higher level event is one with a small probability of occurrence. The designed structure is checked against this event to ensure that ductility requirements and deflections will not be excessive.

Design motion characteristics are a function of site conditions, distance from the most significant seismic sources and the probable event size.

SEISMIC DESIGN CODES AND ANTICIPATED CHANGES

The 1976 Uniform Building Code introduced some major changes into estimation of the horizontal load for seismic design. The soil effect was recognized for the first time by introducing an S factor and requiring computation of a soil period T_S. Further revision is considered with a more direct approach to site and soil effects. This work which is being undertaken by the Applied Technology Council, with funding provided by NSF, has led to suggested new siesmic regionalization maps based on risk concepts and a complete revision of the lateral design force equation. These maps were shown during the Summer Seismic Institute and were part of the selected slides made available for presentation to all those attending the Institute.

SEISMIC DESIGN: STRUCTURAL CONCEPTS

Henry J. Degenkolb

CONTENTS

SITING

Our first problem concerns the siting of the structure. We will assume that the general location of the structure and, therefore, the consequent seismicity of the area has been determined by the use for which the structure must be created. Unfortunately, the most useful economic or socially necessary locations are also those where the foundation conditions may be the worst. Wharves must be located next to water; bridges must cross streams, and sometimes faults; office buildings located in economically concentrated areas which are often in alluvial valleys or at mouths of streams. It is often true that the facility must be located on the least desirable geological locations. When considering earthquakes and the design of the facility to resist them, there are several geologic hazards to evaluate in choosing the site.

FAULT RUPTURE

The first and most obvious hazard is the location of the fault itself as related to the structure. Not all faults rupture the surface of the ground, but come do and typically in California and for the great earthquakes in the West the fault movement can often be traced by surface ground breakage. It is generally thought that anything built across the fault will be torn apart. In 1906, the average offset was about 15 feet with a maximum of 21 feet in Marin County. It is important that potentially active faults be located by field exploration so that structures will not be built on them unless there are other overriding conditions that require the construction to be located there. Unless we are to have a series of islands, for example, bridges, roads, communications, utilities, etc., must cross faults. In pipelines, cables, etc., present designs use loops, flexible joints, etc., to provide enough slack to take up the movement without rupture. It may be possible to provide a mat foundation as shown in Figure 1 or to interconnect the foundation sufficiently to have the structure act as a unit to prevent collapse. This solution has been tried in several cases where the structure could not be moved, but I know of only one case where it has actually been tested. The Banco Central in Managua, Nicaragua sat astride one of the fault breaks that moved in the December 23, 1972 earthquake. The fault went through the building, but the heavy basement which contained the security vaults was so strong and rigid that there was little concrete cracking and the ground movement went around the building rather than through it. However, if at all possible, it would be better to move the structure away from the fault rather than try to build across it.

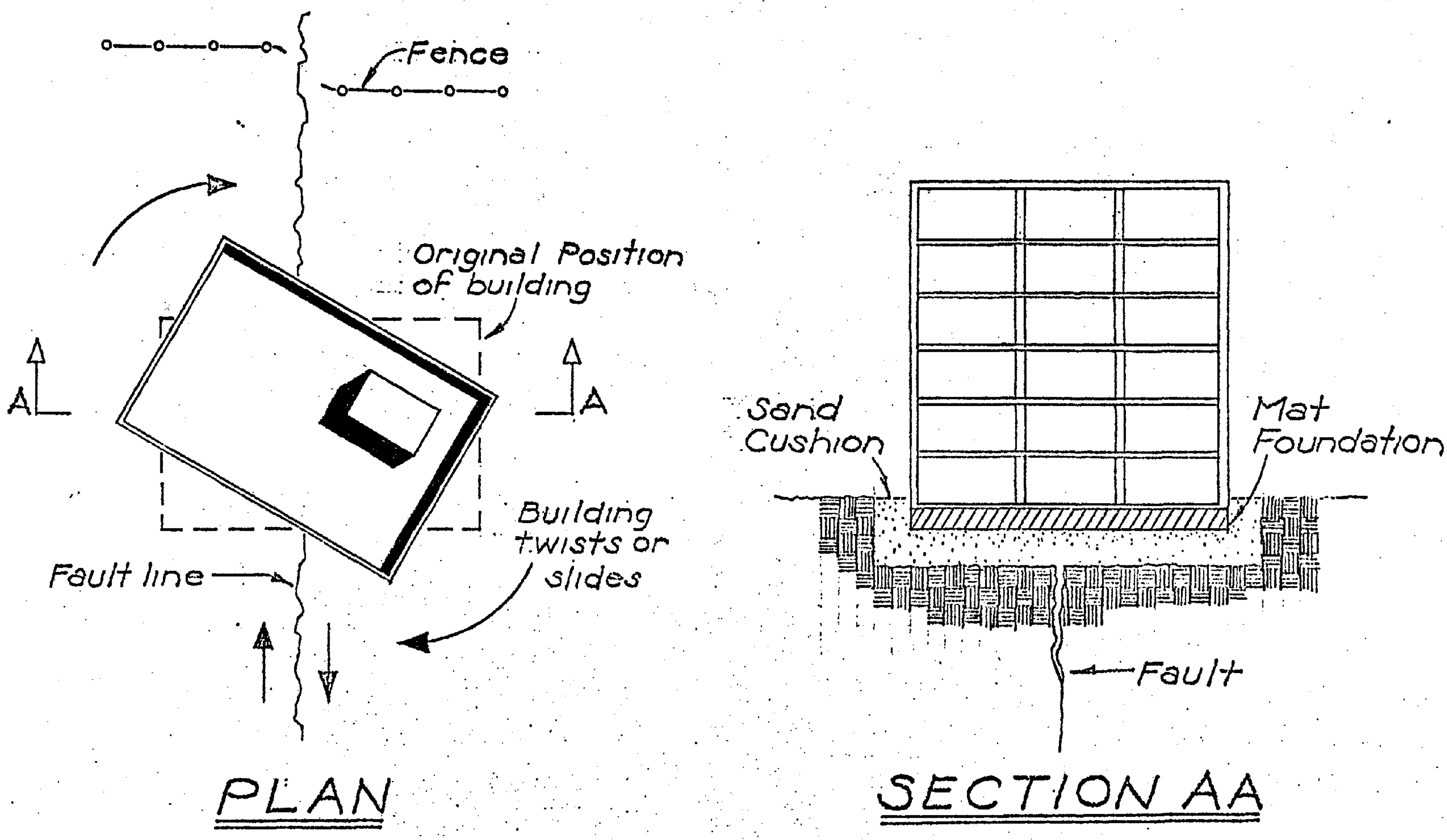

Fence
Original Position of building
A
A
Fault line
Building twists or slides
PLAN
Sand Cushion
Mat Foundation
Fault
SECTION AA

FIGURE 1

LANDSLIDE, CONSOLIDATION, LIQUEFACTION, LURCHING

The next general category of foundation conditions that may seriously affect the stability of a structure during an earthquake involves factors that are all interrelated although we will examine them separately. These involve landslide, consolidation, liquefaction and lurching. Historically, these effects have probably caused the greatest loss of life. They are represented by intensities XI and XII in the Modified Mercalli Scale of earthquake intensity and have caused the most spectacular evidence of earthquake damage such as the Turnagain Slide in Anchorage, 1964, the Peru 1970 earthquake effects (as well as previous Peruvian earthquakes), the damage in Niigata, Japan in 1964 and many less publicized slides in California in 1906. The earthquakes in China in 1556 and 1976 are examples of great loss of life due to ground failures.

The first of the ground failure categories is that of landslide. When the ground shakes, the shearing stresses in the soil increase and the friction to resist these stresses decreases. In many cases the cost of preventing landslide is too great for low cost installations, and the structure should be moved. However, in high cost installations, solutions such as indicated in Figure 2 may be possible. Changing surface slopes to reduce the hazard, the addition of retaining walls or tiebacks, or the reduction of ground water to increase friction may all be possible.

The second of the ground failure categories relates to consolidation of the foundation material under dynamic conditions. For example, loose sand, when shaken may consolidate. A significant change in water level may cause ground to compact. While this rarely causes collapse, the damage to the structure and its function may be extensive. If this possibility is indicated from the foundation investigation, caissons or piles might be used to provide support on a more reliable strata. We have often been able to provide basements, reducing the net pressure on the supporting soil, thereby reducing the tendency to consolidate.

The third category of ground failure, liquefaction, has had extensive publicity since 1964 although the phenomena has been known for 40 years. Certain materials - especially loose granular soils in the presence of water - tend to liquefy when vibrated. They tend to consolidate and free the water. The foundation becomes quick and buildings float and move as happened in Niigata, Japan. The materials prone to exhibit this effect are widely distributed, often near rivers, lakes and bays. These effects can be minimized or eliminated by proper foundation study - using piles, providing basements in structures, grouting or pre-consolidating the material or by some other means as indicated in Figure 3. However, in the present state of the art, we have found that it is difficult to quantify marginal situations. It is easy to tell by a simple inspection that certain soils will not liquefy. It is also easy to state - also by simple inspection - that certain soils are almost certain to liquefy during a strong earthquake. But it is very difficult or impossible to evaluate the large gray area between these two extremes as to how probably the liquefaction may be. A large part of this uncertainty relates to the uncertainty of the magnitude and duration of the

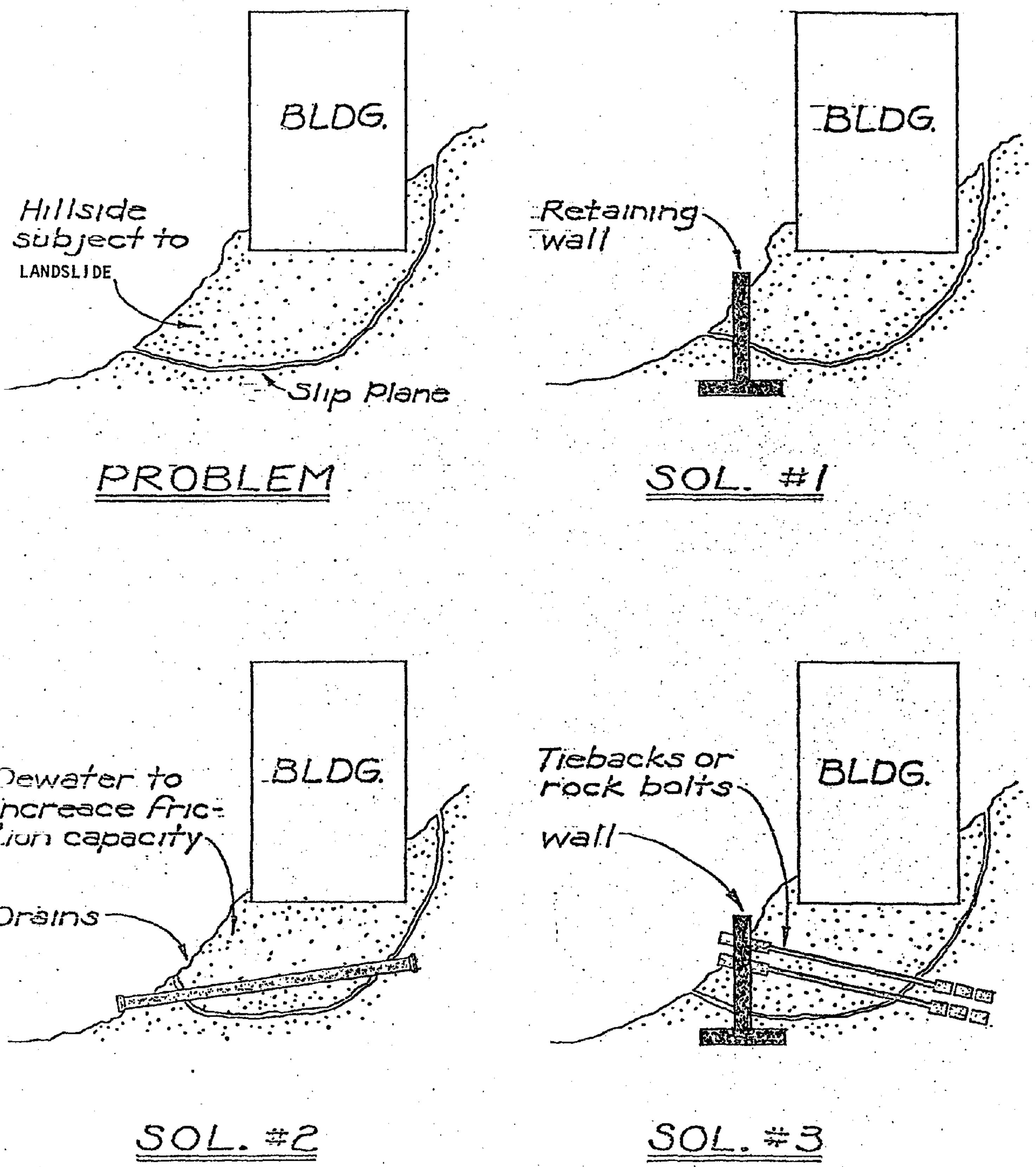

BLDG.
Hillside
subject to
LANDSLIDE
Slip Plane
PROBLEM
BLDG.
Retaining
wall
SOL. #1
BLDG.
Dewater to
increace Fric-
tion capacity
Drains
SOL. #2
BLDG.
Tiebacks or
rock bolts
wall
SOL. #3

FIGURE 2

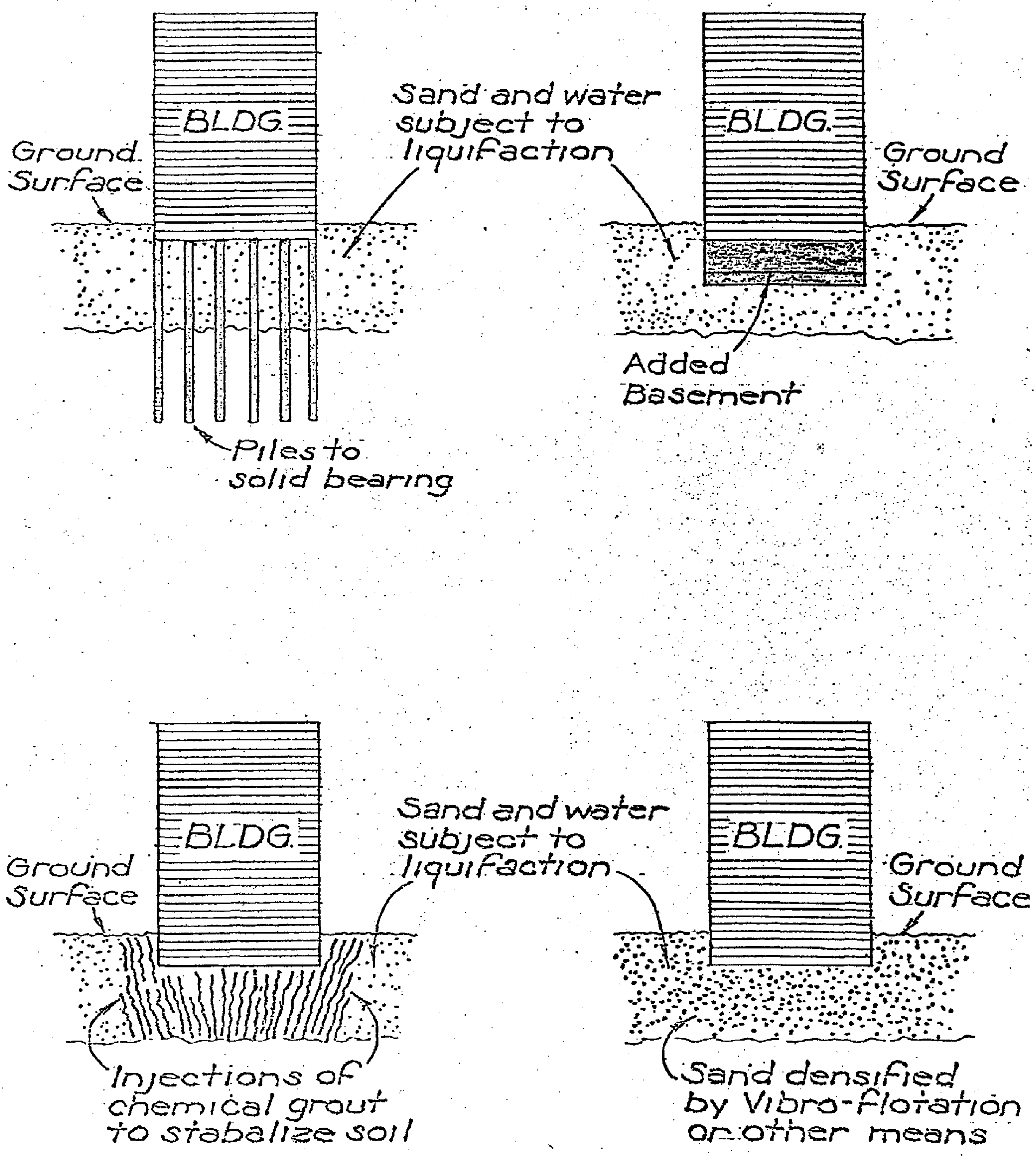

BLDG.
Ground Surface
Sand and water subject to liquifaction
BLDG.
Ground Surface
Piles to solid bearing
Added Basement
BLDG.
Ground Surface
Sand and water subject to liquifaction
BLDG.
Ground Surface
Injections of chemical grout to stabalize soil
Sand densified by Vibro-Flotation or other means

FIGURE 3

ground shaking that may occur. Liquefaction of certain layers of ground is also a major factor in some of the large landslides such as occurred in Turnagain Heights in Alaska.

We often note after an earthquake that there are gaps or fissures in the ground that are not caused by any of the phenomena noted above. As the ground is shaken, tension cracks may appear as portions of the ground tear apart. It would be similar to the effect we observe when a bowl of gelatine (Jello, for example) is violently shaken. The ground does not consolidate nor move downhill or liquefy, but certain discontinuities open up. Personally, I do not think that this is a major problem under a structure if the foundations are well tied together so that the whole structure moves as a unit. The structure provides the tension strength that holds the ground together. But it is a significant reason as to why we need foundation ties.

EXTERNAL HAZARDS

A third category of general hazards from earthquakes should be considered in the siting of structures, but they are beyond the scope of our present discussion. These are external hazards often accompanying earthquakes. In certain coastal areas adjacent to water, tsunami (tidal waves) may have a run-up that is very destructive. These are more often caused by distant rather than near earthquakes. Another external hazard is that of fire following the earthquake. The structure may be especially vulnerable when utilities are broken and firefighting apparatus is unavailable due to structure collapse or the fact that roads and streets are often impassable.

STRONG MOTION VIBRATION

It is the fourth category of hazards caused by earthquakes that concerns us after the structure is sited. It concerns the effects of strong motion vibration upon structures. As the ground vibrates, the structure must move, setting up inertia forces of considerable magnitude. It is the intent of a building code or specification to provide the design parameters to resist these forces. To the extent that they are primarily lateral or horizontal forces, earthquake forces are similar to wind and so require a different concept of structural systems as compared to vertical load forces. And because the design forces occur rarely, earthquake forces, like wind forces, are often treated rather carelessly by the designer.

EARTHQUAKE ENGINEERING BACKGROUND

Before we proceed further, we better review some background on earthquake engineering.

GROUND MOTION

Earthquake forces result from erratic vibratory motion of ground on which the structure is supported. The ground vibrates both vertically and horizontally, but it is customary to neglect vertical components since most structures have considerable excess strength in the vertical direction through the effect of safety factor requirements.

Vibratory motion of the ground sets up inertia forces in the structure, shown in Figure 4. For a rigid structure, ridigly coupled to its foundation, force equals the mass of the structure times acceleration of ground motion at any instant. If the structure deforms slightly, that is, if it is flexible, then for short periods of time, force may be somewhat less because deformation of the structure absorbs some of the energy, storing it for some later time. However, if a very flexible structure is subjected to a ground motion whose period is near that of the structure, a much greater force may result, especially if several cycles of ground motion occur.

In order to eliminate the assumptions inherent with very early, simple harmonic motion studies, M.A. Biot, in 1933, proposed the use of a "spectrum" for evaluating effects of actual earthquake ground motions on simplified structures. The spectrum concept of response to random earth motions has been refined, modified, and greatly expanded by George Housner and his associates at the California Institute of Technology through the use of an analog computer and later with the digital computer.

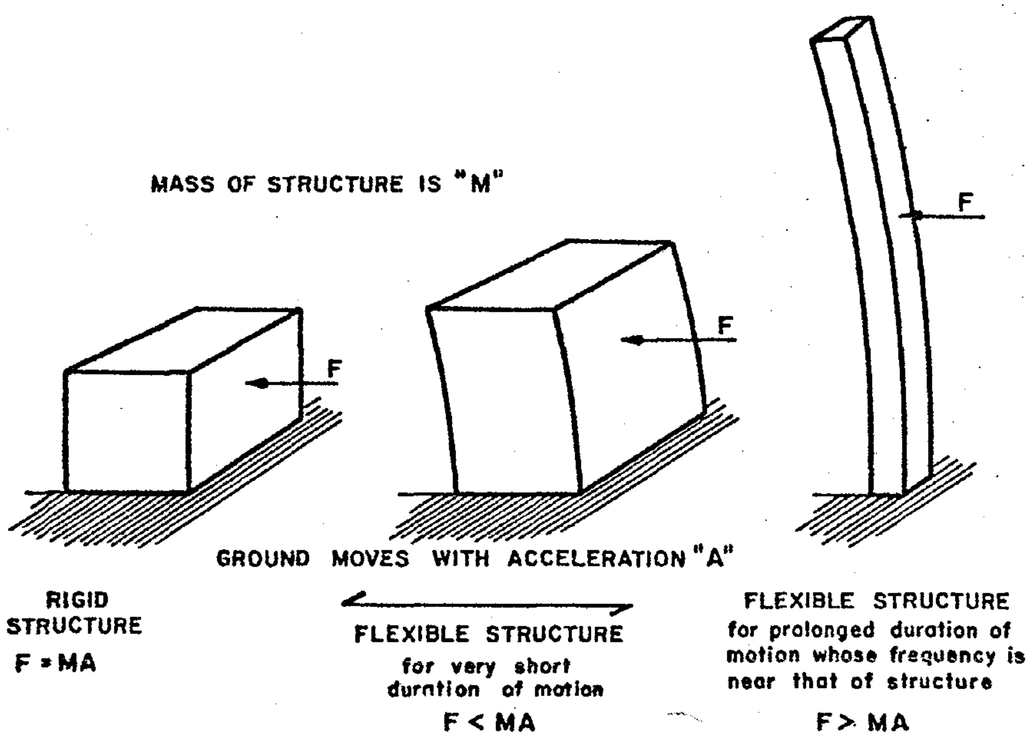


FIGURE 4

Briefly, the spectrum can be visualized by assuming a movable base as shown at the bottom of Figure 5. Fix to it a series of cantilever pendulums with varying periods In this diagram, the length of the pendulums and, therefore, the period, increases toward the right. If the base is moved through the same ground motion that occurred in any given earthquake as recorded by a strong motion seismograph, the maximum response of each pendulum is recorded - that is the maximum response at any time during the earthquake. If the maximum response is plotted against the period of the pendulum, a curve will develop, somewhat as indicated in the solid line shown in Figure 5, although not as smooth. The response may be deflection, shear, equivalent acceleration, whichever is chosen since they are all related. It is perhaps easiest to visualize the response as equivalent acceleration. The response spectrum from many early California earthquakes indicated surprising similarity of shape. Later records from different parts of the world, from different foundation conditions, from various types of faults, and varying distances from faults, show that various shapes of the response spectrum will occur. Vertical ordinates vary with the magnitude of the earthquake and location of the recording instrument. As shown here, the vertical ordinate is relative only. No attempt has been made to relate the response to specific forces or accelerations, since this varies from earthquake to earthquake and from location to location.

DAMPING

Acceleration derived from actual earthquakes are surprisingly high as compared to the forces used in ordinary design, so studies have been made of the effect of different degrees of damping.

Damping reduces the ordinates markedly, as indicated in Figure 5. The damped response curves are similar but the magnitudes are greatly reduced. The first step in deriving earthquake forces for design by analytical methods is to obtain a record of the ground motion during a damaging earthquake.

One of the best - really the only usable one of the early records - was the Seismogram of the 1940 El Centro earthquake expressed as a time-history of the accelerations as shown in Figure 6. It shows a maximum acceleration of about 31% g about two seconds after the earthquake started. Later measurements of strong earthwuakes have been made up to 125% g.

By putting the readings of the El Centro record through a computer process that simulates the operation discussed with Figure 5, we obtain the response spectrum shown in Figure 7 on next page.

In order to determine the required forces we must know or approximate the period of the structure - the time it takes to complete one full cycle of vibration. We will not go into those details - they can be found in various references. However, the period varies with its height, shape, materials of construction, type of framing, weight of contents and many other factors. In general, the practical range may vary from about 0.1 second for a one story building to 5 or 6 seconds

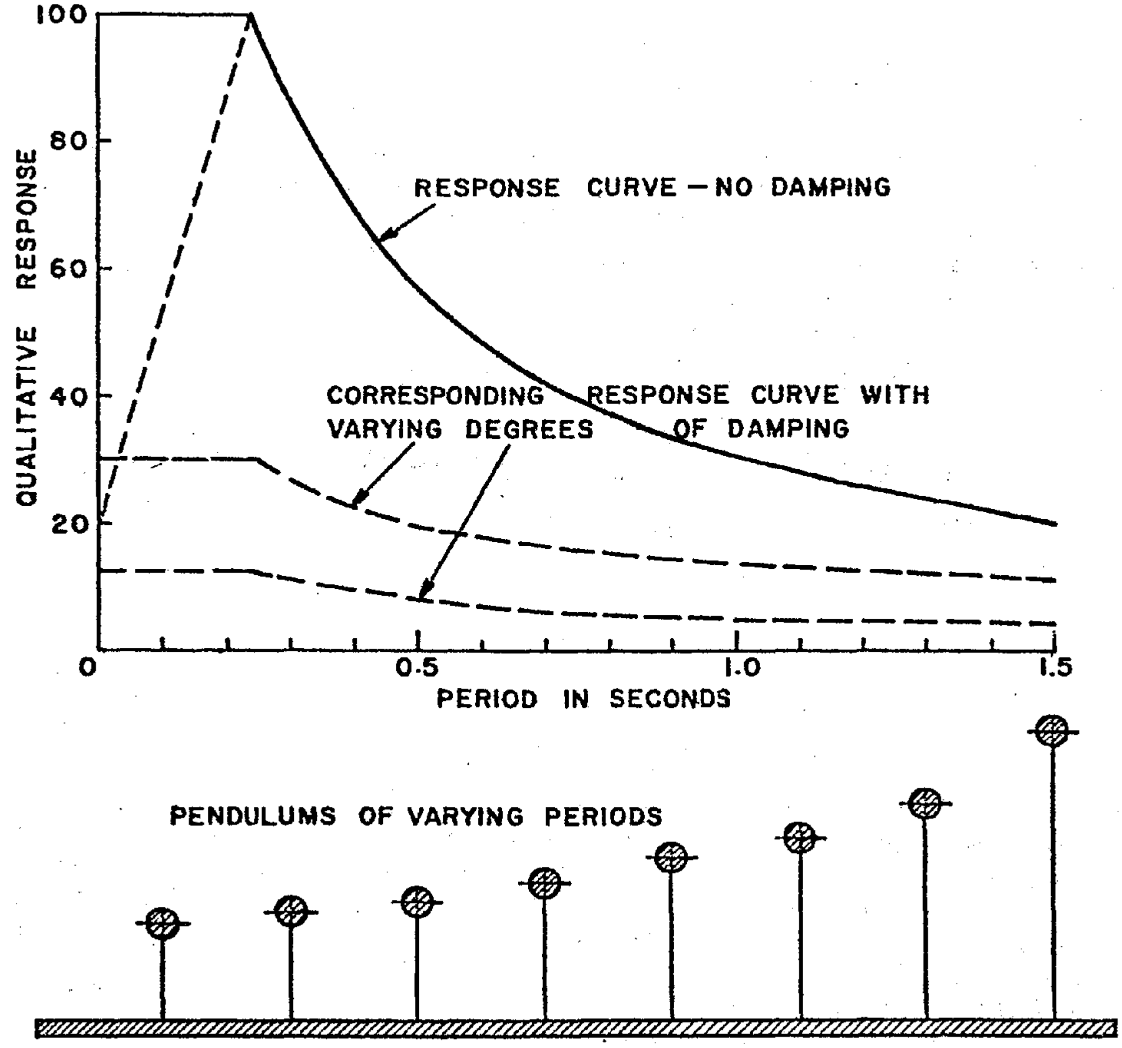


FIGURE 5

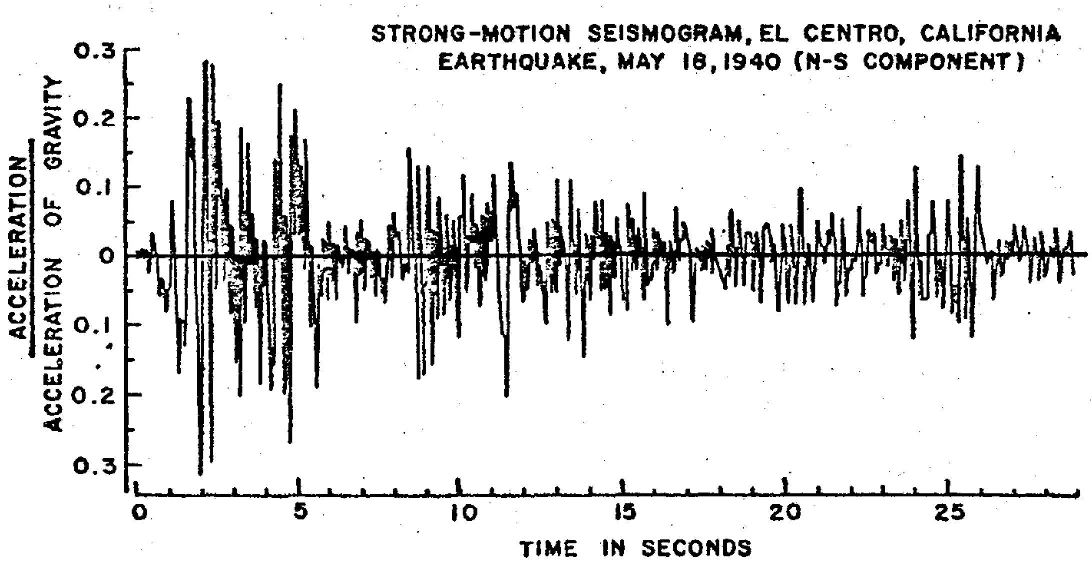


FIGURE 6

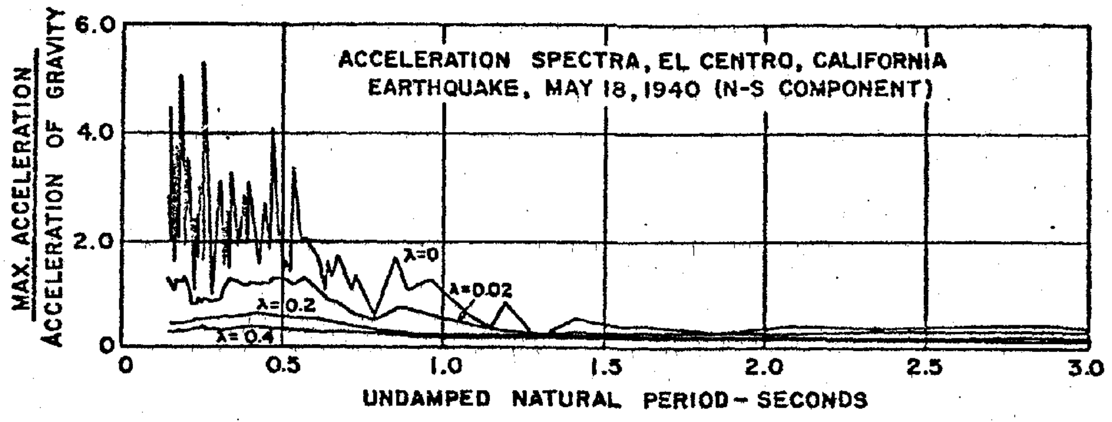


FIGURE 7

or even more for a 40 to 60 story building. Note from the spectrum that the earthquake with a 31% g ground acceleration amplifies to an undamped response of 500% g and even about 100% g at 5% damping for a structure in the three to seven story range. At a 100% g response, that would be like trying to design a building that projects horizontally from a cliff. Experience with our common construction materials indicates that such high design forces are not necessary. The difference of the high analytical forces as compared to the performance of structures designed to much lower forces can be explained to a large extent by a material property we call ductility.

DUCTILITY

For example, if we consider a structure where the resisting element is an unreinforced brick pier as shown in Figure 8(a), it will react exactly as the reinforced concrete column of (b) up to a certain point. At that time it will fail as a brittle material. The concrete bent, however, will continue to resist forces at much greater deflections. We know from experience in earthquakes that (a) will fail early while (b) will stand up longer in the earthquake. A steel bent would last even longer. The difference in this performance is related to the ductility of the system and the design code forces are reduced from the theoretical code forces to allow for this action.

The ductility that is required is illustrated in Figure 9. If our structure is made of a sufficiently strong elastic material, and subjected to the ground motion of the design earthquake, it would respond at a load and deformation at level "B". However, our material is not strong enough to be loaded to that level; its yield point is at level "A" and, idealistically it can be assumed that the stress strain curve is horizontal after that - it deforms plastically. If the material can

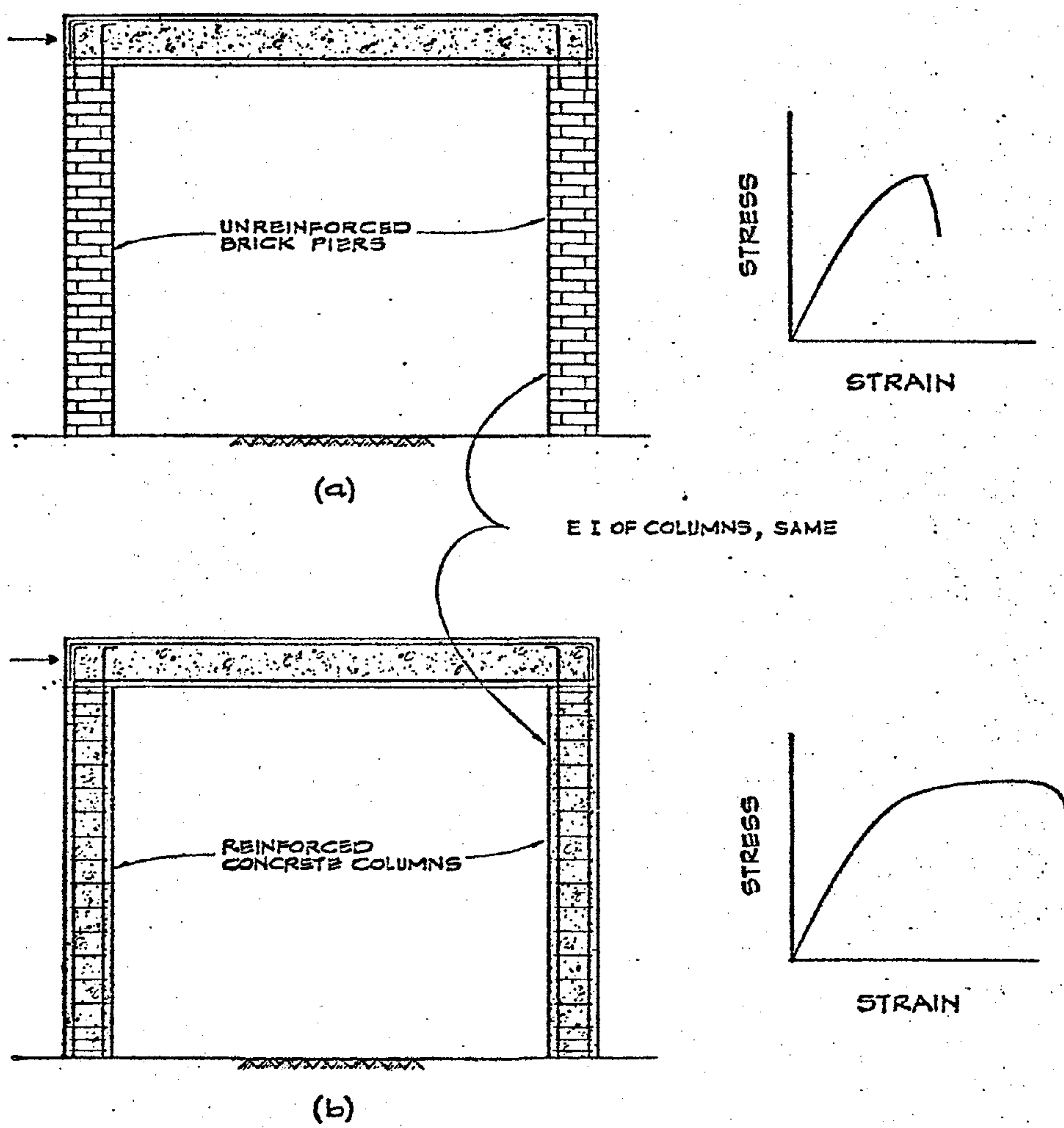
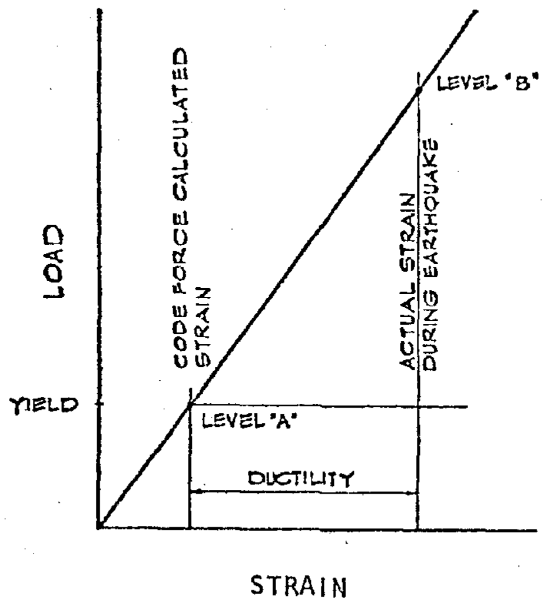

UNREINFORCED BRICK PIERS
STRESS
STRAIN
(a)
E I OF COLUMNS, SAME
REINFORCED CONCRETE COLUMNS
STRESS
STRAIN
(b)

FIGURE 8

be deformed plastically far enough, it has been shown that the weaker, but ductile structure would deflect the same amount as the strong elastic structure; at least for single mass systems. So for a material to withstand that design earthquake, if it has a yeild point at level "A", it must have enough ductility to be deflected to the level "B" position without failure. As a corollary with this condition, if we provide code level forces at level "A" by tacitly accounting for the ductility, we must recognize that the actual deflections or drift of the structure in that design earthquake will be several times the code force amount - out to level "B". For current codes depending on materials, etc. this may be from two to ten times.



CALCULATION OF DUCTILITY REQUIREMENTS
AND DEFLECTION OR DRIFT

FIGURE 9

With the base shear forces now determined, these must be translated into loads at various levels of the structure, but this operation is not pertinent to our concerns at this point. For a simplified but yet more detailed discussion than we have time for at this point, we would suggest that you refer to the little booklet - "Earthquake Forces on Tall Structures" that is available from Bethlehem Steel Company.

DESIGN PROBLEMS

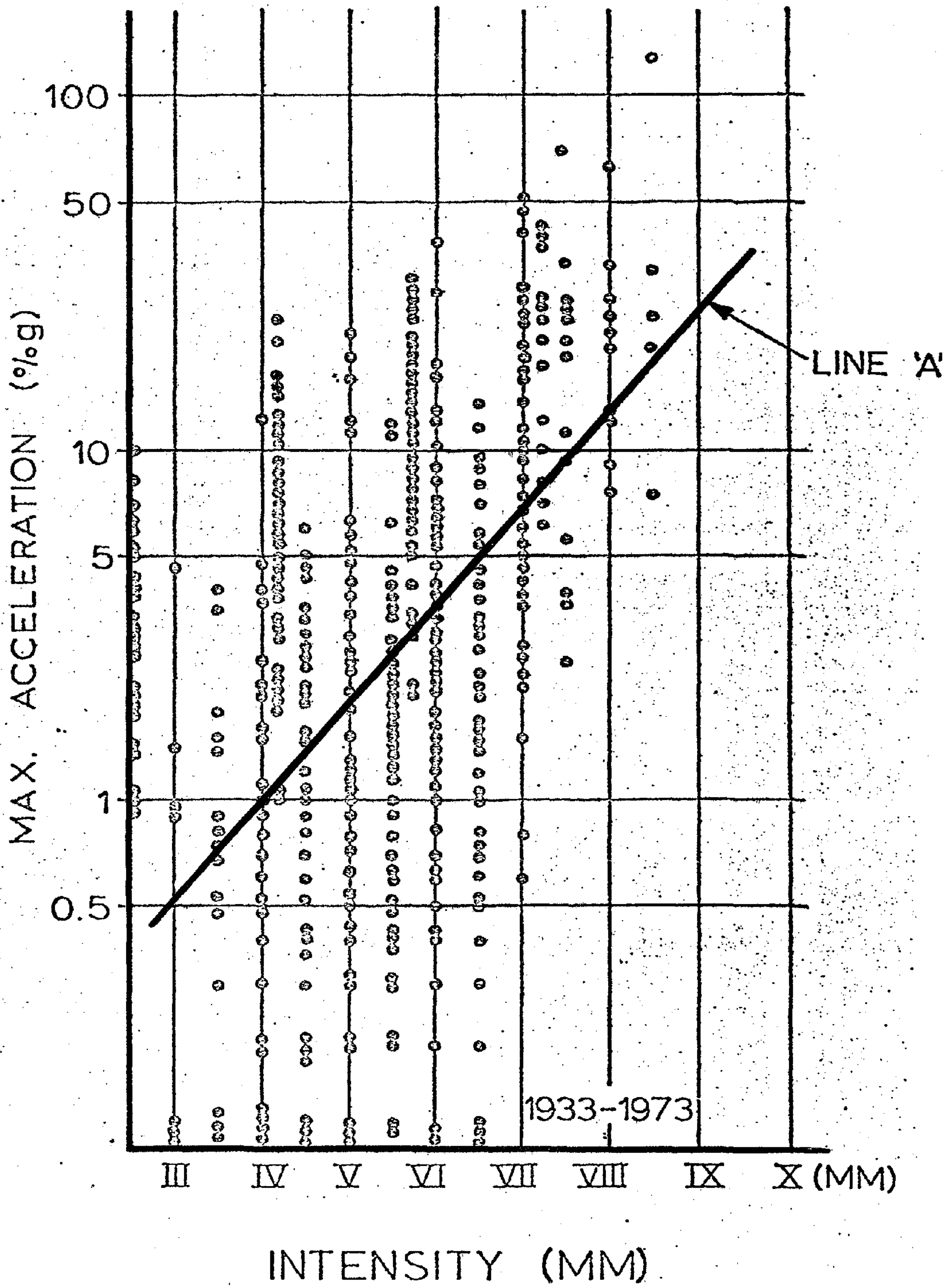
With the above as a background, we can now more closely examine the design problems of earthquake engineering. The basic problem has its source in the fact that it is much more demanding of the engineer because we are dealing with unknown loads, meager information or material properties and the performance of the structure is determined in the ultimate load range rather than at service loads.

As far as the Structural Engineer is concerned, the most important aspect of earthquake engineering is this basic difference from all other structural design. Our design forces are only a small fraction of the forces expected to be exerted on a structure in a major earthquake. In other words, the structure will be overstressed many times as defined by usual design standards.

The structure must remain coherent and stable at deformations of many times the yield deflection. This observation, in turn, means that in designing to resist earthquake forces, we not only have to consider specific forces and loads i.e., provide certain minimum strengths (as in most structural engineering design), but we must also consider the performance at great overloads and large deformations. This affects joint and member detailing to assure that the structure will hang together at large deformations and affects member proportions so that less critical elements fail first and absorb energy and so help to protect the more critical members such as columns. This must be emphasized over and over again: In earthquake resistant design, it is not sufficient or adequate to make a member "strong enough" it must also have a reserve of ductility. The whole concept of structural design changes.

I wish we had time to discuss in detail the various items of quantitative uncertainty that make our structural forces indeterminate in addition to being so large - many times our design forces. However, let me mention just a few such as the uncertainty of the effect of earthquake magnitude and distance, the effect of the type of fault causing the earthquake, quantitative effect of different foundation conditions such as depth and quality of alluvium as compared to rock, configuration of ground surface and of rock surface, length of time of shaking, the uncertainties surrounding the actual digitizing and analysis of the few strong motion records we do have, and the lack of strong motion records of major design earthquakes.

The engineering literature has nice formulae for the relationship of all of these factors and the unsuspecting engineer may be misled by the precision with which they are all tabulated. All of these relationships are so crude that they are at best a possible - not probable - first approximation as to what the motion might be. Figure 10 shows a plot of one parameter - accelerations as related to earthquake intensity.[(1)] And yet our present studies and research values pretend that these points all lie on line "A", and our computers work with great precision to determine a structural response for the assumed motion determined by that line. This means it is all the more important to consider the performance at ultimate; which in essence here means that we must provide ductility and stability. Without further discussion, let us merely state at this time that the earthquake forces that our structures must resist are not only many times our code specified forces, but they are highly indeterminate, based on our present ground motion data and present analysis techniques.



100
50
10
5
1
0.5
MAX. ACCELERATION (%g)
LINE 'A'
1933-1973
III
IV
V
VI
VII
VIII
IX
X (MM)
INTENSITY (MM)

FIGURE 10

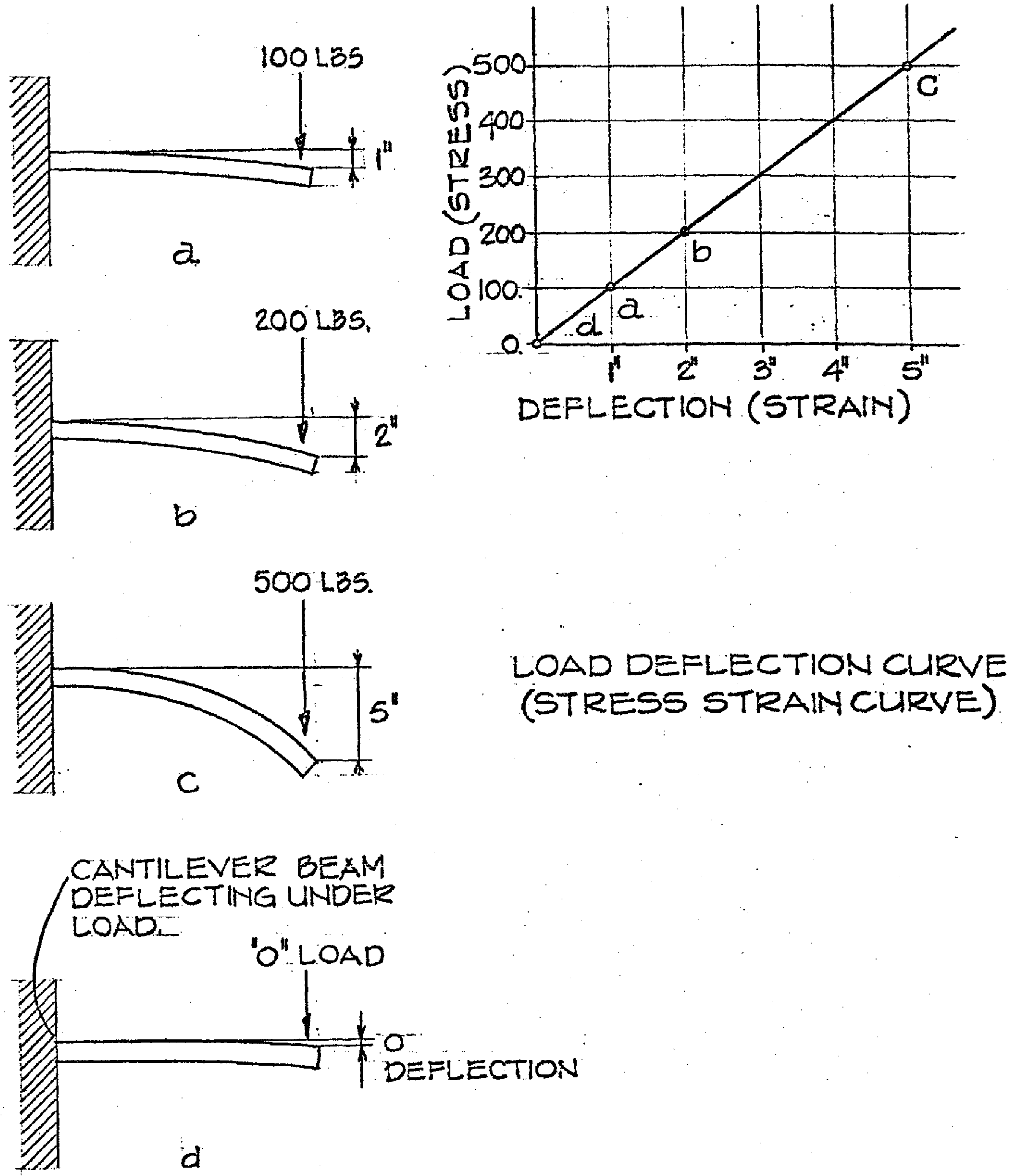
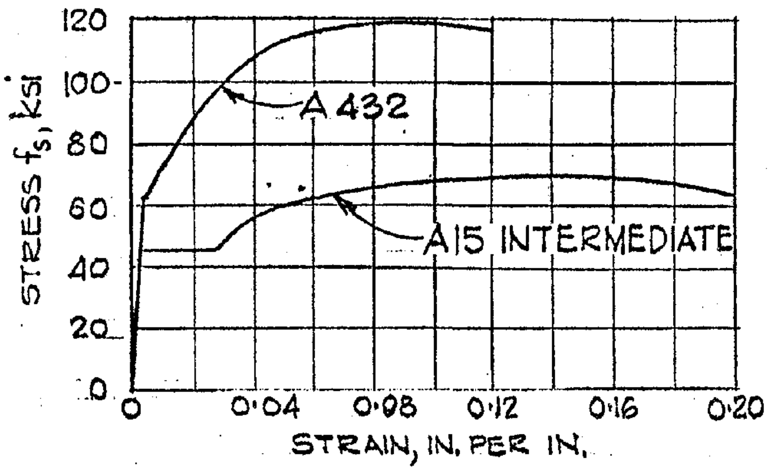
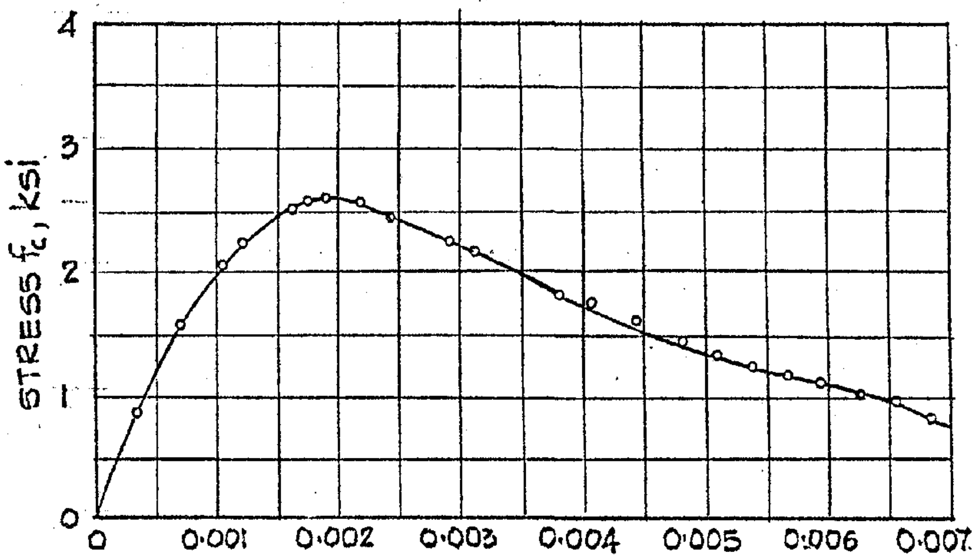

100 LBS
1"
a
200 LBS.
2"
b
500 LBS.
5"
c
CANTILEVER BEAM DEFLECTING UNDER LOAD
"O" LOAD
O DEFLECTION
d
LOAD (STRESS)
500
400
300
200
100
0
DEFLECTION (STRAIN)
1"
2"
3"
4"
5"
LOAD DEFLECTION CURVE
(STRESS STRAIN CURVE)

FIGURE 11

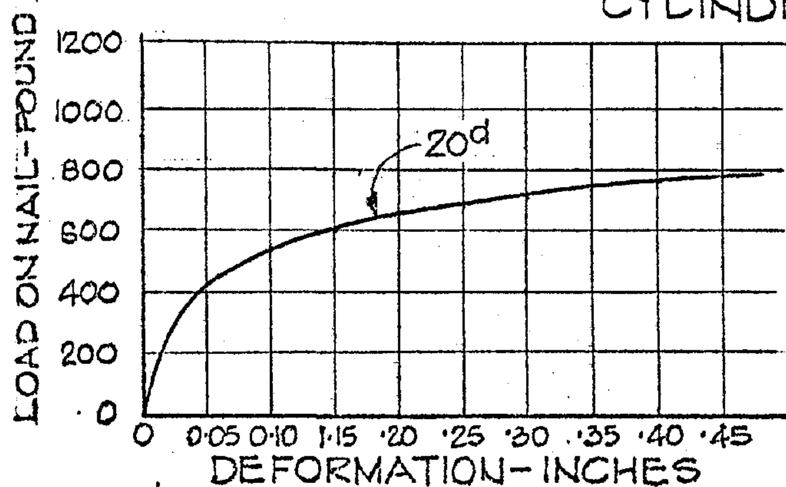


2 GRADES OF REINFORCING STEEL



TYPICAL CONCRETE COMPRESSION CYLINDER.

20^d – 915 lbs. AT 0·875" AT ULTIMATE LOAD.



TYPICAL 20^d NAIL IN DOUGLAS FIR ⊥ GRAIN

FIGURE 12

TYPICAL STRESS – STRAIN CURVES

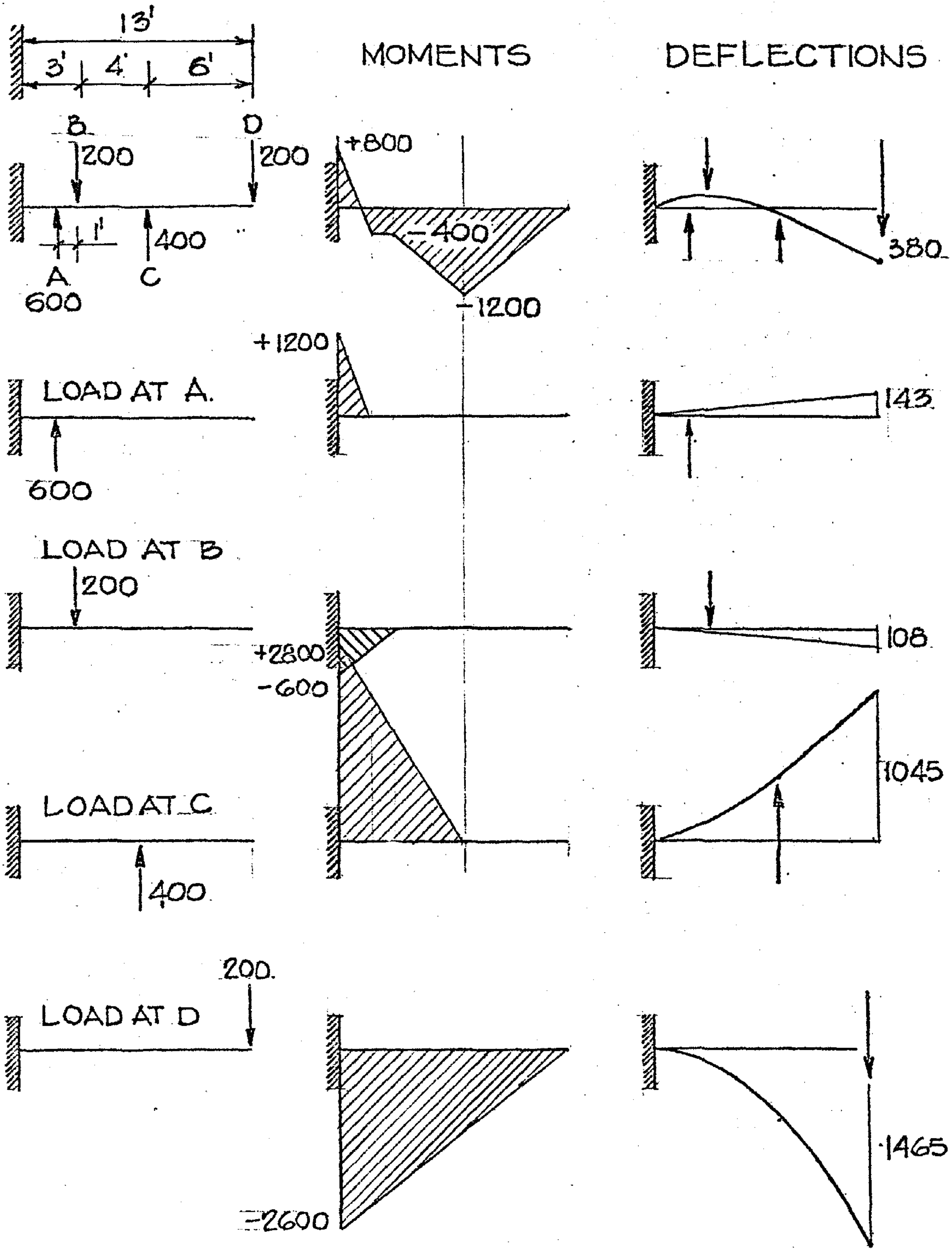
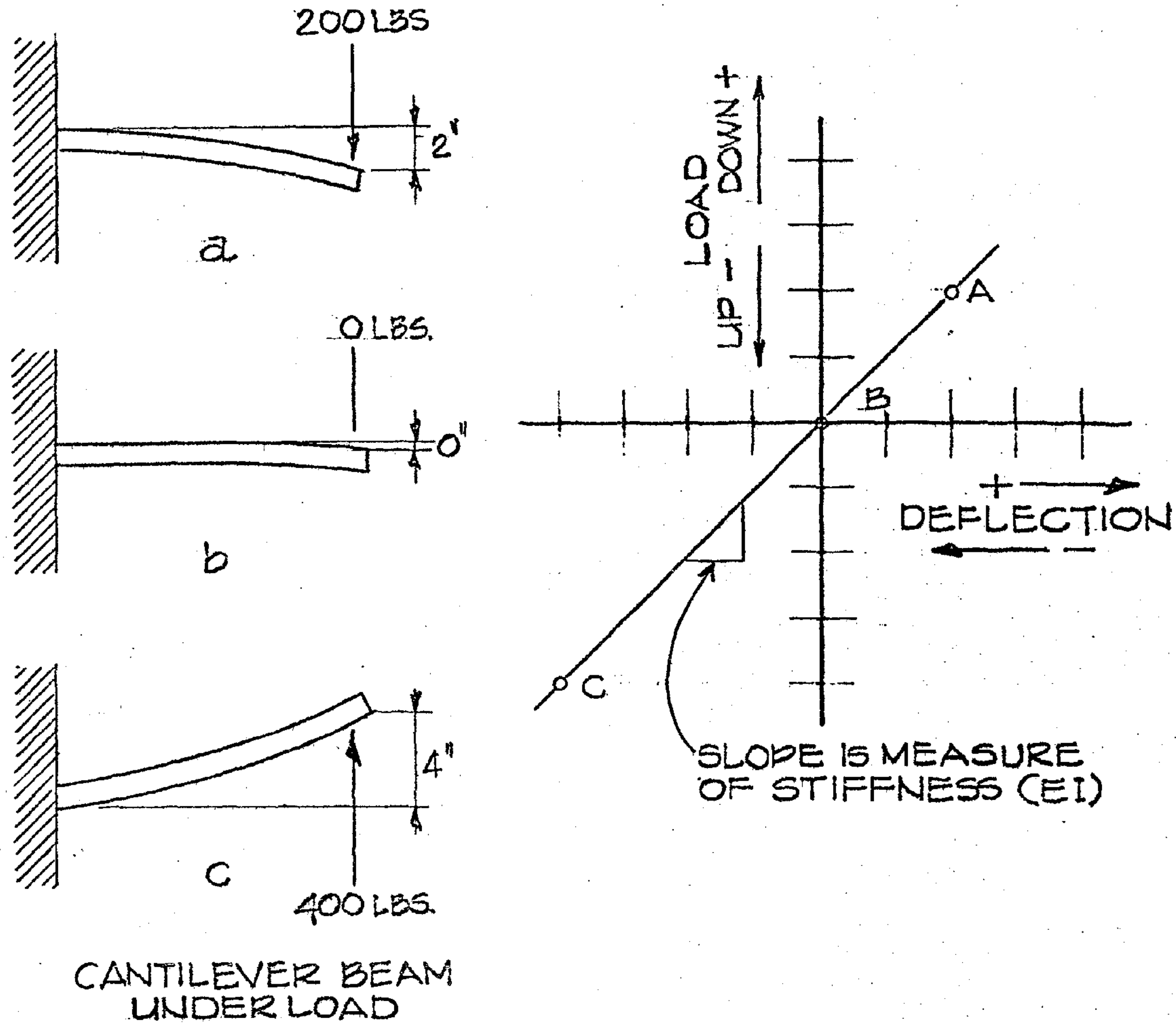


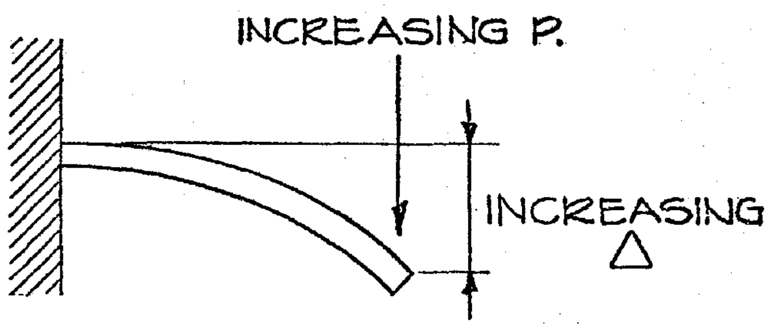
FIGURE 13 - SUPERPOSITION



LOAD DEFLECTION CURVE

LOAD FOR BOTH DIRECTIONS
(HYSTERESIS CURVE WITHIN ELASTIC RANGE)

FIGURE 14



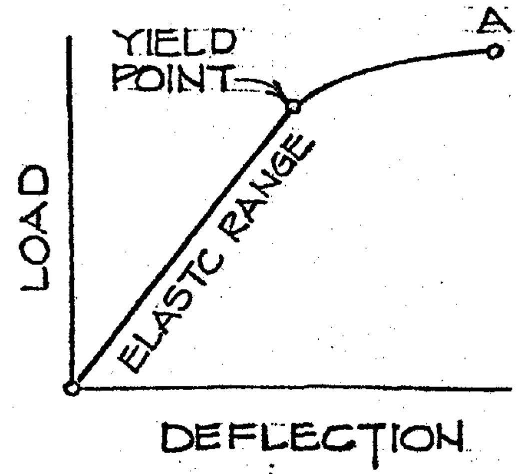
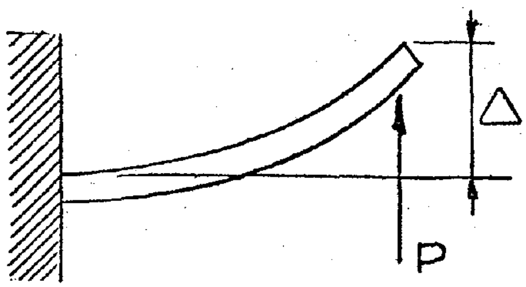


FIG. 15a



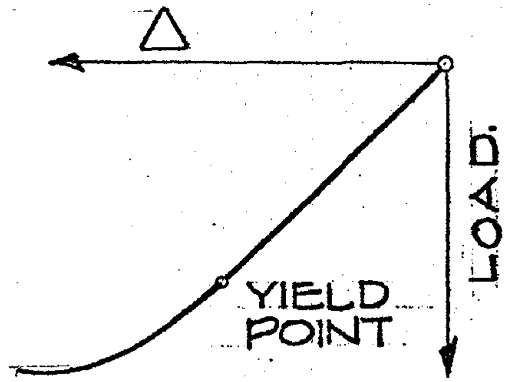
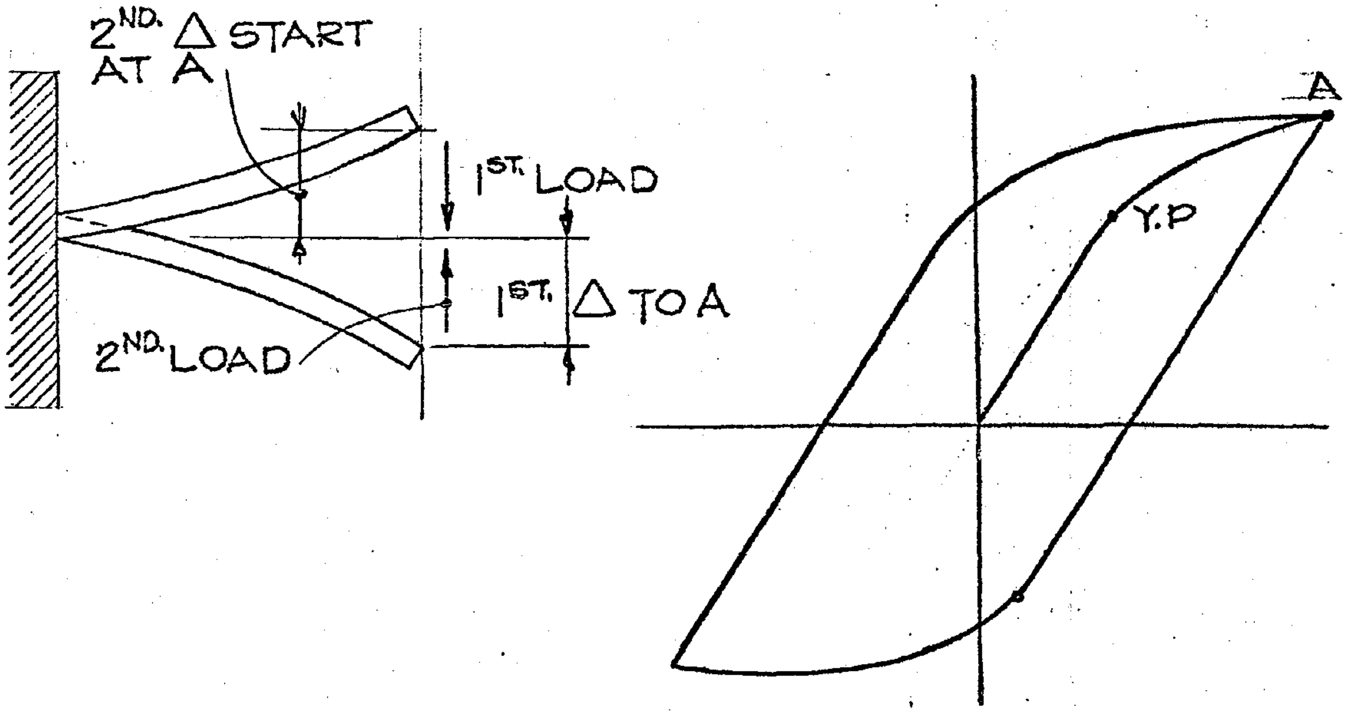


FIG. 15b



HYSTERESIS CURVE
LOADS BEYOND Y. P.

FIG. 15c

If our forces are unknown, how about our knowledge with regard to analysis and material performance? Here the situation is but little, if any, better due largely to the necessity of working in cyclic loadings far into the plastic range rather than the monotonic elastic basis with which most engineers are familiar.

BASIC ENGINEERING CONCEPTS

Before we go any further, let us quickly review some basic engineering concepts. We have to be sure we know what engineers consider to be the usual methods of design before we can discuss the differences that are necessary for earthquake resistant design.

The first usual assumption is that materials are elastic or nearly enough so that they can be considered elastic. If a beam deflects one-inch under 100 lbs. of load, it will deflect 2-inches under 200 lbs. and 5-inches under 500 lbs. of load, as shown in Figure 11. This relationship can be plotted in a stress-strain curve which is a straight line. Typical stress-strain curves of some materials are shown in Figure 12, where we use the material only to a working stress that lies on the straight part of the curve.

Under these conditions we can treat complicated combinations of loads by analyzing each one separately and combining the effects as shown in Figure 13 through the principle of superposition. When the loads are removed, as in Figure 11, the structure returns to its original position.

For all practical purposes in the type of structures we are considering, we can neglect fatigue effects in the elastic ranges of stress we are discussing. Also the direction of load, as long as we stay within the elastic range. So when we place an alternating load on the beam as shown in Figure 14, we can draw the stress-strain curve in two directions from the origin and we have a hysteresis curve which is merely a straight line where the slope is a measure of the stiffness.

Of the hundreds of thousands or millions of tests that defined our use of materials, practically all were concerned with the usable portion of this stress-strain curve plus the maximum load that the material would carry. This was especially true for columns where buckling was generally considered the point of failure and testing was stopped shortly after buckling occurred even though this may have been at a point much higher than the required design load.

When we go beyond the yield point, the material or beam takes a permanent set. Now when we draw a stress-strain curve for a ductile material we get a curve as shown in Figure 15(a). If we loaded it in the opposite direction, we get the curve as shown in Figure 15(b). But if we first load it in one direction and <u>then</u> in the opposite direction, we get a loop curve where the beginning of the reverse curve is at a point "A" of the first curve. By continuing the cyclic loading we obtain the hysteresis curve of a ductile material as shown in Figure 15 (c) where the area of the curve is a measure of the work done on the material.

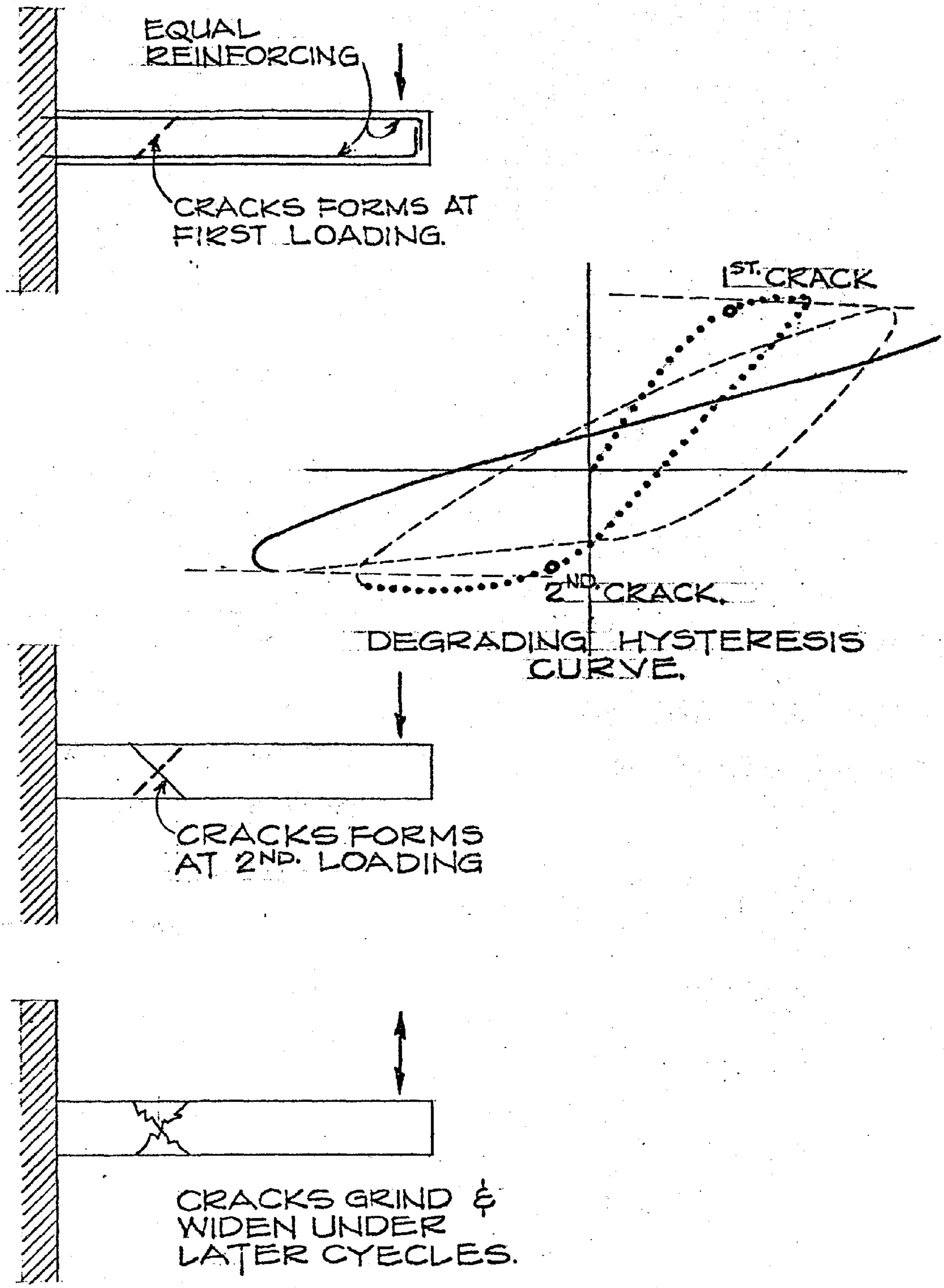

EQUAL
REINFORCING
CRACKS FORMS AT
FIRST LOADING.
1ST. CRACK
2ND. CRACK.
DEGRADING HYSTERESIS
CURVE.
CRACKS FORMS
AT 2ND. LOADING
CRACKS GRIND &
WIDEN UNDER
LATER CYECLES.

FIGURE 16

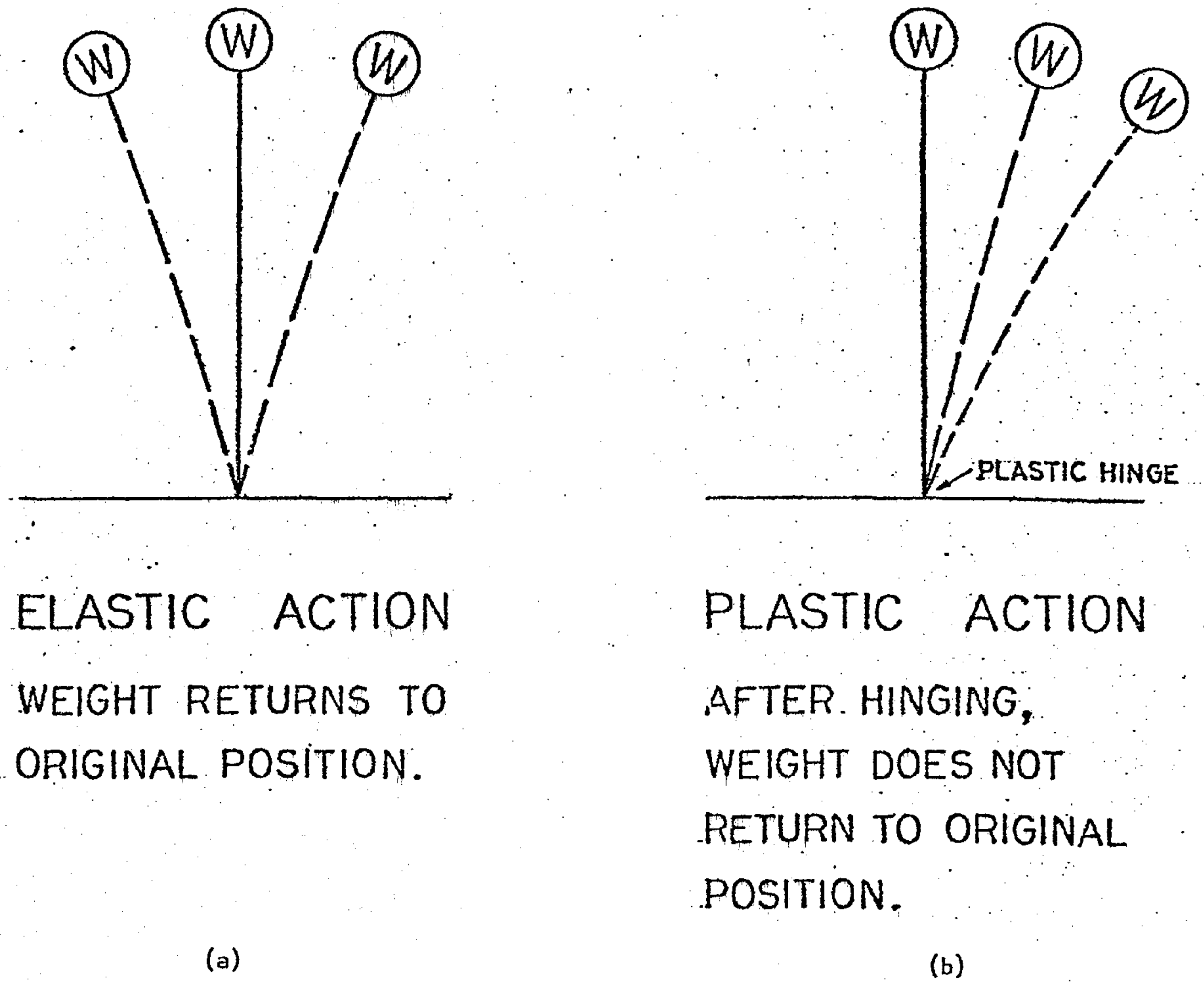

PLASTIC HINGE
ELASTIC ACTION
WEIGHT RETURNS TO ORIGINAL POSITION.
(a)
PLASTIC ACTION
AFTER HINGING, WEIGHT DOES NOT RETURN TO ORIGINAL POSITION.
(b)

FIGURE 17

Some materials deteriorate under this cyclic loading into the range beyond the elastic limit. If we take a reinforced concrete beam and load it into that range, a crack forms and the beam becomes less stiff as shown in Figure 16. When the reverse loading is applied a movement takes place along this crack which permits more deflection for each cycle of loading and the beam becomes progressively "looser" with each cycle. This is called a degrading hysteresis curve.

SEISMIC DESIGN CONSIDERATIONS

With this background in mind, let me cite just three examples of problems that most research engineers as well as designers do not consider when working with cyclic loadings with loads that are well beyond the yeild point range.

CRAWLING EFFECT

First, there is the "crawling" effect and the length of time of shaking. When dealing with elastic systems as in Figure 17(a), it is not important if the ground does not return to its original position, nor is it important that motion in each direction be similar and equal, nor is the time of shaking important. If the system remains elastic, when the ground stops moving, the top of the structure returns to its normal position above its base and when the motion stops, there is no residual stress of deformation. However, when the structure goes into the plastic region as in Figure 17(b) it does not return to its zero position unless an impulse of equal size and length of time and in the opposite direction is immediately applied. Since earthquake motion is erratic, this rarely, if ever, happens. For example, there could be a large sudden motion in one direction that causes permanent deformation of the structure. The return motion could be a series of smaller or slower motions that do not stress the structure beyond the elastic limit. If the base motion then stops the structure has a permanent deformation. If this process is repeated - say as a result of a series of violent jerks in one direction and rather gentle motions return - the structure deformation keeps increasing to the point where stability is affected by the so-called P-Δ effect. Obviously, if there is this tendency to "crawl" then the length of time of shaking becomes important as Jennings and Husid[2] at Cal Tech found. This length of time effect does not show up on the response spectrum.

LENGTH OF TIME OF SHAKING

It is thought that the length of time of shaking is related to the length of the fault break because as energy is released along the fault,[3] the induced vibrations arrive at any given point at different times. This is due to the appreciable time it takes for the break to travel along the fault and for the differences in time it takes for the vibrations to travel the varying distances from those points to the single location of the structure under discussion. The length of fault break is also related to the magnitude of the earthquake, increasing in length as the earthquake gets larger. Present relationships are shown in Figure 18. Therefore, the larger earthquake tends to shake the ground for a longer period of time than a smaller earthquake.

P-Δ EFFECT

Earlier, we briefly mentioned the P-Δ effect. In the elastic range of structural deformations, the extra bending moments and stresses caused by the fact that the vertical load is eccentric with the columns or foundations is usually rather minor and negligible as compared to the primary lateral force loads. After the yield point is reached, however, and the structure deforms the large amounts associated with the required ductility, this P-Δ factor becomes quite important and, in fact, can become the direct and primary cause of failure. This is especially true when the load-deflection hysteresis curve degrades as the structural material is damaged and its resistance to load is lowered. If a weakening material is coupled with the "crawling" effect noted earlier due to unequal excursions into the plastic region, it is easy to see that if the motion is prolonged, a complete collapse is inevitable.

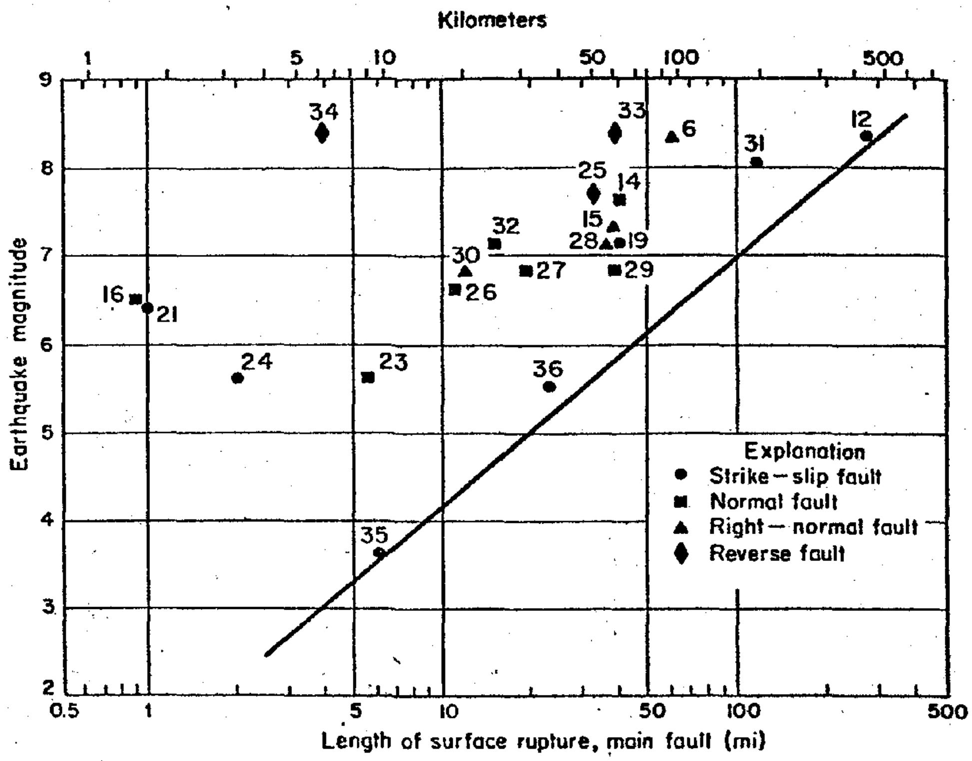
Structural engineers are used to working in the elastic range and consequently, the principle of superposition of loads is ingrained in our thinking. For example, in elastic systems, the stresses and deflections caused by simultaneous horizontal and vertical loadings can be separated into a horizontal system and vertical system and the results can be correctly added to arrive at the result of the combination loads as shown in Figure 19.

Much early research work on plastic response of frames was done on this same principle. It was simpler, easier and used much less computer time to merely analyze the frame with only the lateral cyclic loadings to determine the location of hinges and the necessary ductility factors (amount of rotation capacity) necessary for the frame to remain stable. Work by Anderson and Bertero [4] at the University of California shows this to be untrue, even when the P-Δ is neglected.

For example, in Figure 20 when lateral loads are combined with vertical loads, the hinge will form first at "A" and may or may not form at "B". In either case, rotation will be greater at "A". When lateral loads are reversed, "A" will unload but a hinge will form at "B" before "A" becomes plastic. The rotations will be greater at "B" than for "A" at equal deflections. Under the condition of a hinge at one end and not the other, a positive moment results at "C" from lateral forces - a phenomenon that does not exist when considering lateral loads only in the analysis. Neither of the hinges at "A" or "B" fully recover from the negative (downward) rotation of the hinge, so the beam takes a downward set as indicated at "C", and eventually a third hinge may form there.

The results of one dynamic analysis showing the hinge location for one frame are shown in Figure 21 taken from Anderson's and Bertero's work. [4] Note that hinges are now found in the center of some girders.

Length of surface rupture on main fault as related to earthquake magnitude.



From Chapter 3 - Surface Faulting and Related Effects
M. G. Bonilla

IDEALIZED RELATION BETWEEN MAGNITUDE AND LENGTH OF SLIPPED FAULT

Magnitude	Length (miles)
8.8	1000
8.5	530
8.0	190
7.5	70
7.0	25
6.5	9
6.0	5
5.5	3.4
5.0	2.1
4.5	1.3
4.0	0.83
3.0	0.33
2.0	0.14(735′)
1.0	0.05(270′)
0	0.018(100′)

From Chapter 4 - Strong Ground Motion - G. W. Housner

FIGURE 18

Magnitude - Fault Length Relationships

(From "Earthquake Engineering" Robert L. Weigel, Editor)

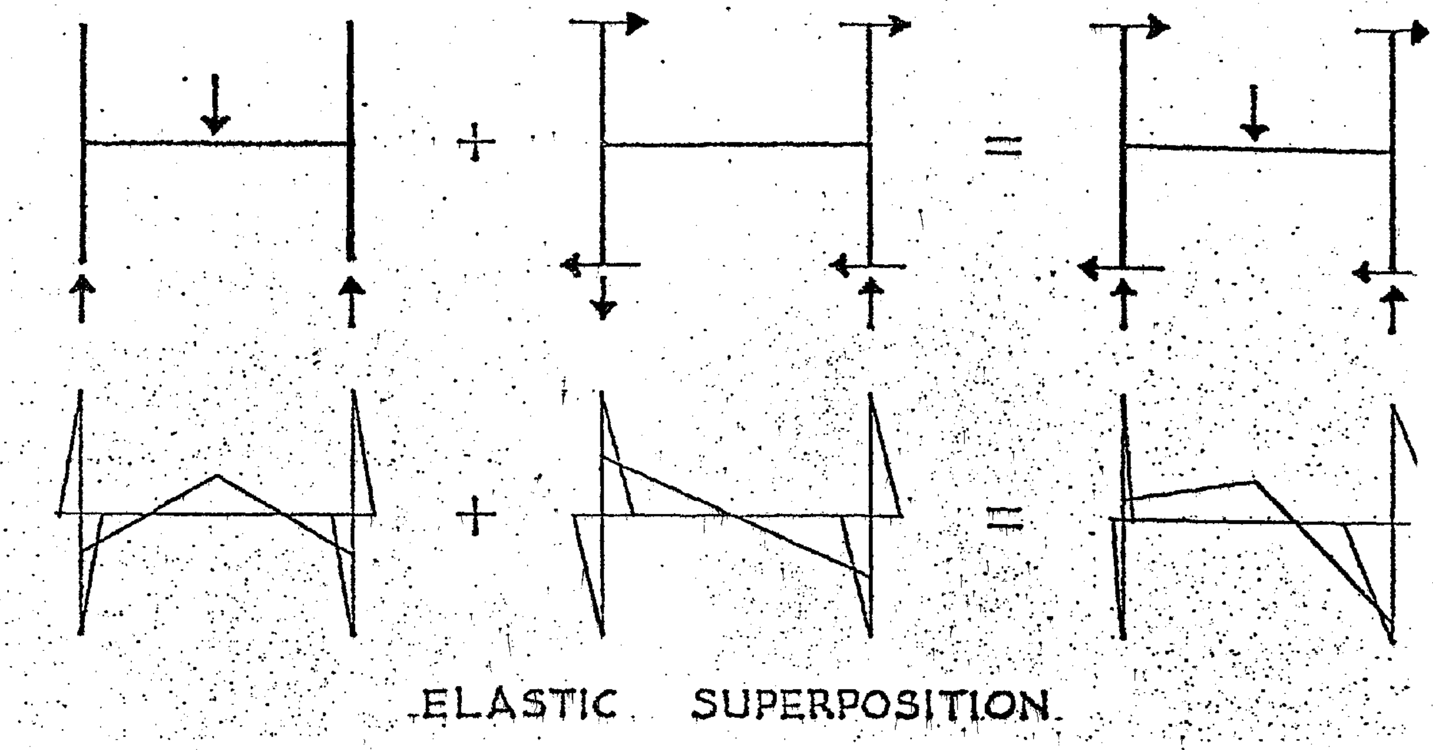


FIGURE 19

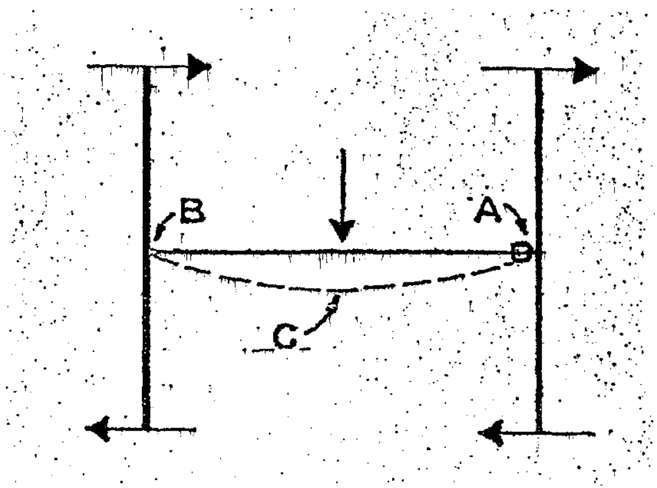


FIGURE 20

Fig. 4-67 Plastic Hinge Location, MWD Frame

FIGURE 21

To illustrate how this can occur, we have prepared the following example.

In considering the modal analysis as is usually performed - with lateral load effects separated from the vertical load effects - it must be remembered that the precise figures that come out of the computer have little relation to reality. To illustrate this effect, let us examine the portion of a structure shown in Figure 22. Assume a 10 foot high section of a one bay building between points in inflection of the columns, with a 24 foot span girder. To keep things simple, assume a concentrated 20 kip load at the center and 10 kip per column lateral force. The columns are sized so no hinge can form in them and the girder is sized for a 120 foot kip hing capacity. Rigidity of columns is assumed sufficient so that the girder can be considered fixed at the ends. The girder deforms with a simple elasto-plastic stress-strain curve and we will neglect secondary (P-Δ) effects. If these were combined in a completely elastic manner, the vertical forces and moments as shown in (a) can be combined with the lateral forces and moments as in (b) to give the combination shown in (c). This is the combination that we would tabulate in the office with the usual computer readout and we would list stress factors of 0.33 at the left, 0.50 at the center, and 1.33 at the right of the girder. If we reversed the lateral load direction, the moments would be reversed and the left end of the girder would have a stress factor of 1.33, with both ends of the girder forming equal hinges.

When these forces are combined in a ductile structure whose girder hinging capacity is 120 foot kips, we obtain the result shown in (d). Since the maximum girder moment in 120 foot kips, we obtain the result shown in (d). Since the maximum girder moment is 120 foot kips, the maximum right-hand column shears cannot be more than 12 kips, so the remainder of the 20 kip story shear - 8 kips - has to go into the left-hand columns, giving a girder moment of 80 foot kips. Using these girder end moments to obtain the center moment of the girder we get 40 foot kips. The resulting loads and moments can be compared to those of (c) and while they are different, they may not be alarming in this case. Now let us remove the lateral load with the results shown in (e). Since the change is now all in the elastic range - comparable to the starting point of the first reversal in the hysteresis diagram - we can subtract (b) from (d) to obtain (e). This vertical load condition can now be compared to (a) and we note that the moments and forces have changed considerably - a center moment of 100 foot kips in the girder as compared to (a) and we note that the moments and forces have changed considerably - a center moment of 100 foot kips in the girder as compared to 60 foot kips, etc. This additional center moment can cause quite a bit of damage to partitions due to increased deflections.

As a matter of interest we can now add the lateral forces of (b) in the opposite direction to the "at rest" moments of (e) to obtain (f) where the frame stays just within the elastic range and the hinge does not form at the left-hand of the girder. In summary on this point, it can be seen that quite different results can be obtained where the vertical load effects are included and that while the elastic analysis can yield a good insight into performance if viewed with caution, the precise figures that come out of the computer can be substantially different from the "true" conditions.

In Anderson's and Bertero's work, the relative influence of considering lateral loads alone as against lateral combined with vertical loads on the column ductility is shown in Figure 23.

SUMMARY

At this stage, we should summarize the reasons for the drastic change in the philosophy of structural design in earthquake country as compared to design in other areas.

In most regions, the engineer designs for specific, known loads or conditions to a specified level of safety.

In earthquake prone areas, he is designing for an unknown condition which has to be approximated by past experience, observation, intuition and certain legal standards coupled with those special practices that enable a structure to remain stable at strains much beyond the yield point. A summary of the unknowns and uncertainties that limit a rational mathematical approach as the sole criteria of design are as follows:

A. Lack of data on the actual ground motions for the size and type of earthquake that our buildings must resist.

B. Foundations or geological conditions have a profound effect on structural performance, but at present there is no usable, clear-cut method to correctly express the effects of quantitatively.

C. Analytic techniques are not yet able to handle the many complexities and uncertainties involved in the true dynamic performance of a structure. Some of the problem areas that may lead to erroneous results are:

   1. Necessity to assume the base line of the primary field record of strong motion. This may -

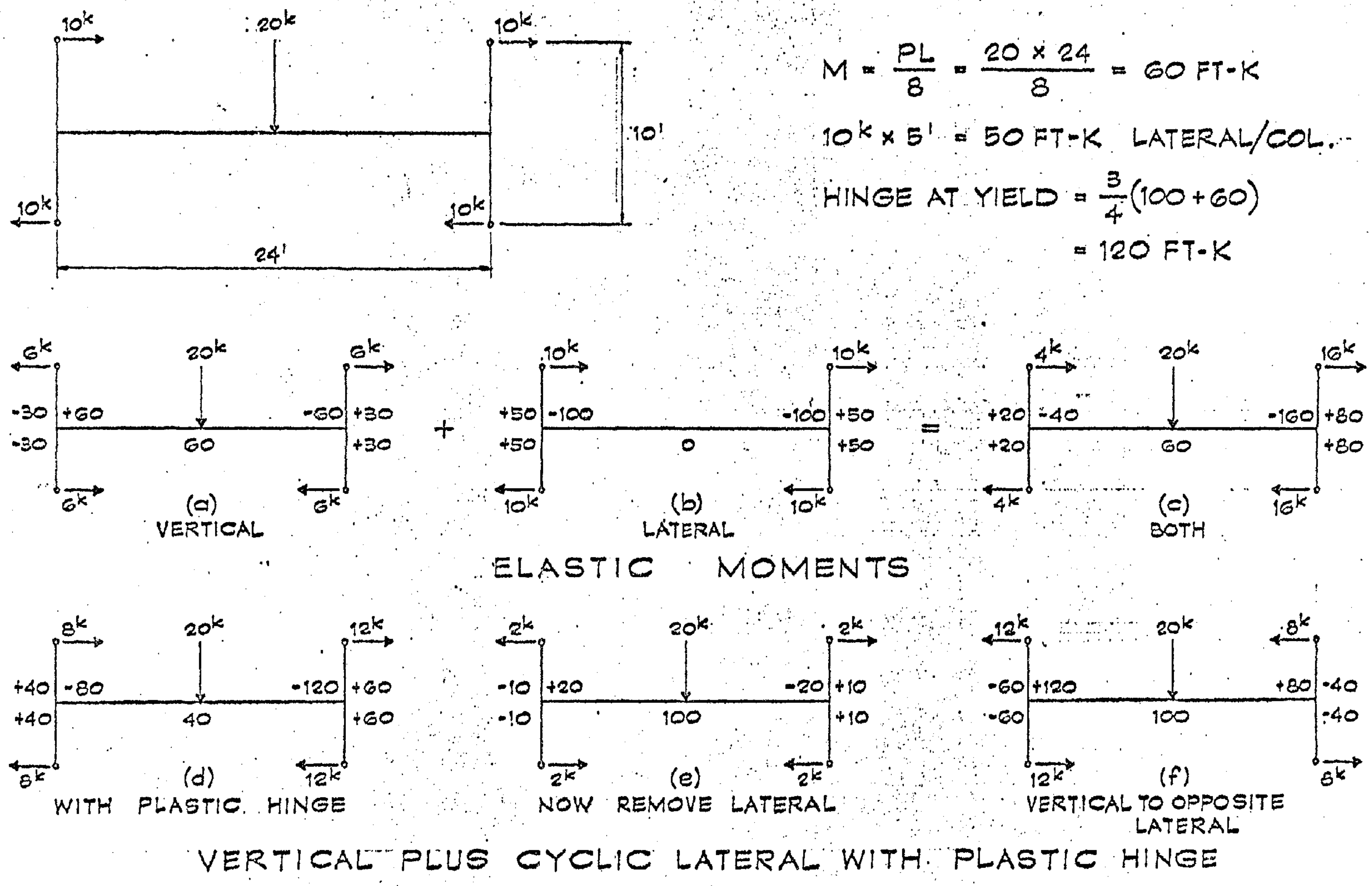
   2. result in "crawling" - permanent increasing deformation - of a plastic structure.

   3. The importance of the length of time of shaking is not indicated on the response spectrum and as a result -

   4. The P-Δ effect becomes important and this has been neglected in much analytical and experimental work to date.

   5. The often used assumption of superposition of loads, stresses, and deformations is not applicable to plastic structures.

Even with what we do know, with the records available and with the analysis techniques available, we know that the code specified forces <u>will be exceeded</u> in the actual structure by a factor of several to many times, not a minor percentage.



10k
20k
10k
10'
10k
10k
24'
M = PL/8 = 20 x 24 / 8 = 60 FT-K
10k x 5' = 50 FT-K LATERAL/COL.
HINGE AT YIELD = 3/4(100 + 60)
= 120 FT-K
6k
20k
6k
-30 +60
-30
60
-60 +30
+30
6k
6k
(a)
VERTICAL
+
10k
10k
+50 -100
+50
0
-100 +50
+50
10k
10k
(b)
LATERAL
=
4k
20k
16k
+20 -40
+20
60
-160 +80
+80
4k
16k
(c)
BOTH
ELASTIC MOMENTS
8k
20k
12k
+40 -80
+40
40
-120 +60
+60
8k
12k
(d)
WITH PLASTIC HINGE
2k
20k
2k
-10 +20
-10
100
-20 +10
+10
2k
2k
(e)
NOW REMOVE LATERAL
12k
20k
8k
-60 +120
-60
100
+80 -40
-40
12k
8k
(f)
VERTICAL TO OPPOSITE LATERAL
VERTICAL PLUS CYCLIC LATERAL WITH PLASTIC HINGE

FIGURE 22

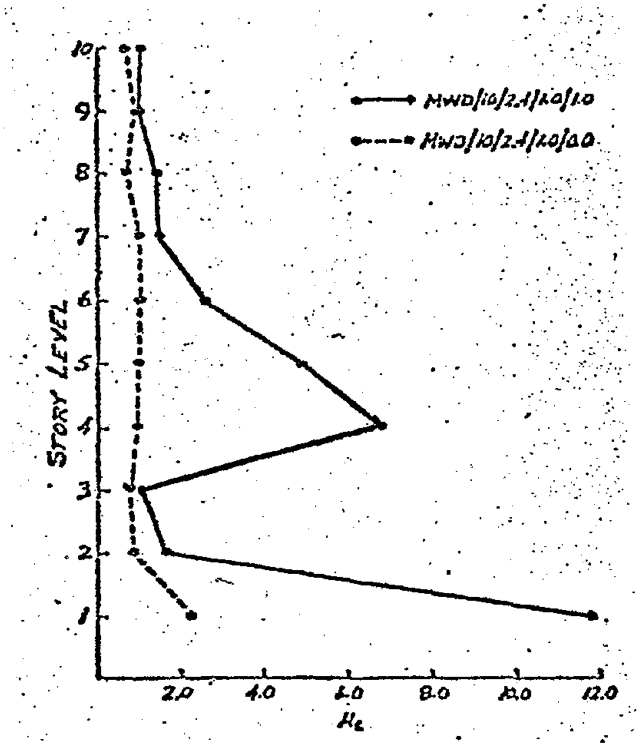


Fig. 4-49 Column Ductility

(From Reference 4)

FIGURE 23

This is contrary to practice in any other field of engineering and has been justified only on the basis of experience with certain types of framing and details that meet the requirements of the code specified forces are entirely unsuitable for use in areas subject to major earthquakes. And some constructions, because of their inherent flexibility, ductility and stability are entirely safe even though they do not meet specific code requirements.

With the above observations in mind, it might be thought that there is no point in trying to design a structure to resist earthquakes - the engineer just does not have enough data on which to base a reasonable design.

In our present age of sophisticated analysis, computers and a variety and excellence of construction materials, we tend to forget that the engineer has continually faced the dilemma of inadequate research before. Many of our most cherished old buildings were constructed before dependable methods of analysis were invented. I have always been intrigued by the old bridge builders who built usable timber bridges of over 200 foot spans long before the stresses could be analyzed. Two Swiss carpenter brothers, Johannes and Hans Grubenmann, built a 364 foot span timber bridge in 1755. I understand that they had contracted for 193 foot and 171 foot adjoining spans, but to see if it could be done, they spanned the whole 364 feet with a gap over the interior support. Eventually the 364 foot span deflected enough so that it became two spans. But engineers have often been required to deliver results before adequate techniques and materials were available.

There are many other similar examples in history such as cathedrals, aqueducts, assembly halls, etc. In order to have built these structures, the engineer had to have an appreciation and pride in his work, an honesty in its execution and a basic knowledge and common sense that could be applied to the problem. It is this combination of what I call professionalism that seems to be deteriorating these days - expecially in the field of earthquake engineering. In some other areas of structural engineering our loads and resultant stresses and consequent performance complete with deflections, safety factors and long term creep, if any, are well known. They are known so well that precise, definite and complete standards of practice can be formulated. A competent design can be performed by a technician by following certain rules and procedures.

In many other areas, including especially earthquake engineering, such knowledge and precision is lacking. Yet the practices that are associated with those areas where knowledge is extensive are carried over into the field of earthquake engineering.

With the above background to give us some understanding of the problem, we can examine some of the specific practical problems that a designer faces in choosing those characteristics of his future building that will improve earthquake resistance.

FRAMING

First, let us consider types of framing. When considering various types of buildings, there are four general types of framing that can be considered. These are diagrammatically illustrated in Figure 24.

ALL MOMENT FRAME

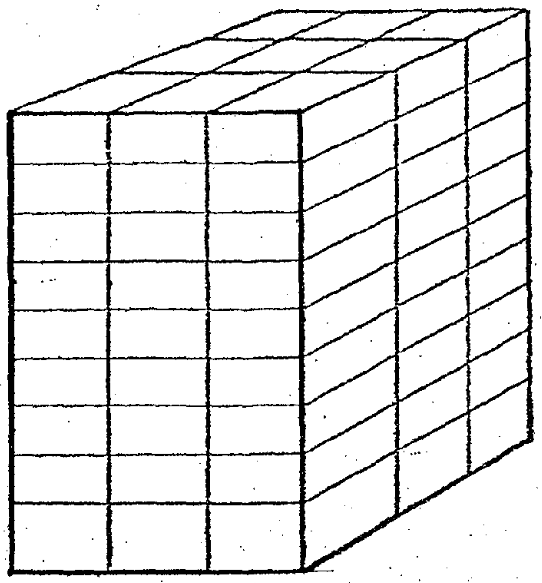
First there is the all moment frame as shown in (a). This is the system most often treated in the literature and has received the most research attention. It consists of columns and girders with moment connections, whereby all lateral forces are resisted by bending of the columns and beams. The discussions presented earlier on the degrading hysteresis curves were presented in terms of this style of framing although the basic principles are applicable to all lateral force design.

The old fashioned concept, on which the present codes were based is shown in Figure 25, wherein all columns and all beams and girders were moment connected for their proportion of the lateral load. This type of framing was given a K factor of 0.67, which somewhat conflicted with the concept of reserve energy or ductility since it had no back-up system of framing that could take over after the primary or stiffest system had failed. This was rationalized by the 1959 Joint Committee that assigned the "K" values because of the extreme redundancy. There were the examples of the bombed-out buildings in England during World War II that successfully stood up even with columns missing.

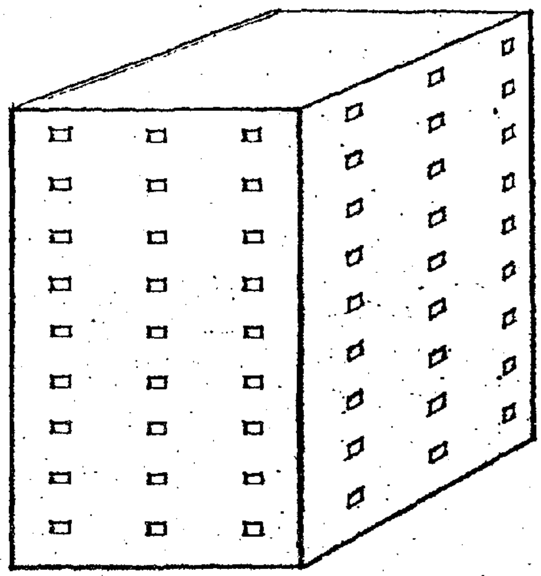
here were many paths for the forces to go - so the failure of one or two members was not important. However, in the everyday practice of engineering for practical, usuable buildings, there are always some minor columns around stairs, elevators, vent shafts, etc., where columns carried only minor loads, so in the interests of practicality and common sense, the provision was stated in the SEAOC Code that <u>all</u> columns did not have to have moment connections, but the desinger could choose his lateral forces resisting system.

With this loophole provided in the SEAOC Code, the systems shown in Figure 26 started to appear and now are accepted as the most common practice. The exterior frames are moment connected in the plane of the wall for the full lateral force, but all other connections are simple connections. A great deal of the redundancy that was counted on for the reduced K value disappeared. This has been carried to the extreme shown in (b) where <u>any</u> failure in the lateral force resisting system almost guarantees the failure of the structure.

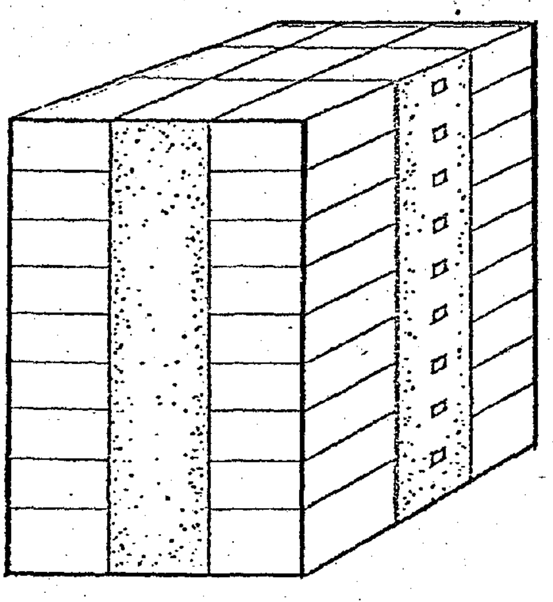
With the "clean" systems, little damping, and light curtain wall framing typical of this framing method, there is little or no reserve strength and little redundancy. There has been <u>no</u> experience with this system in major earthquakes in tall buildings. When we consider the deficiencies in the panel zone for both strength and stiffness and the neglect of the $P\cdot\Delta$ effect in the usual analysis for this type of building, it is most probable that this framing method is due for some major disasters



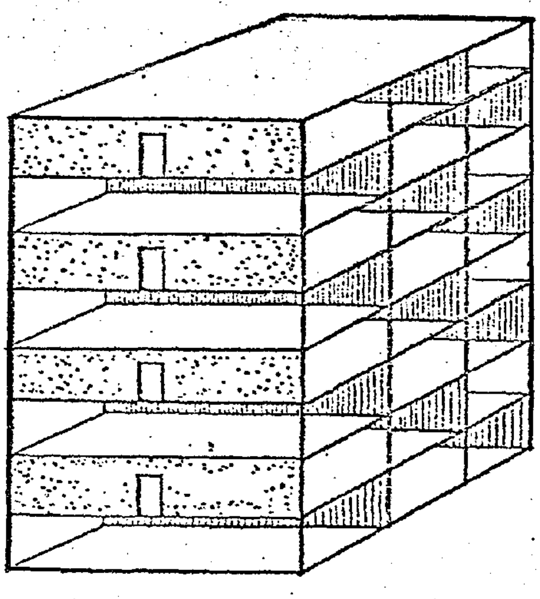
(a) ALL MOMENT FRAME
K = 0.67



(b) ALL SHEAR WALL
OR BRACED FRAME
K = 1.33



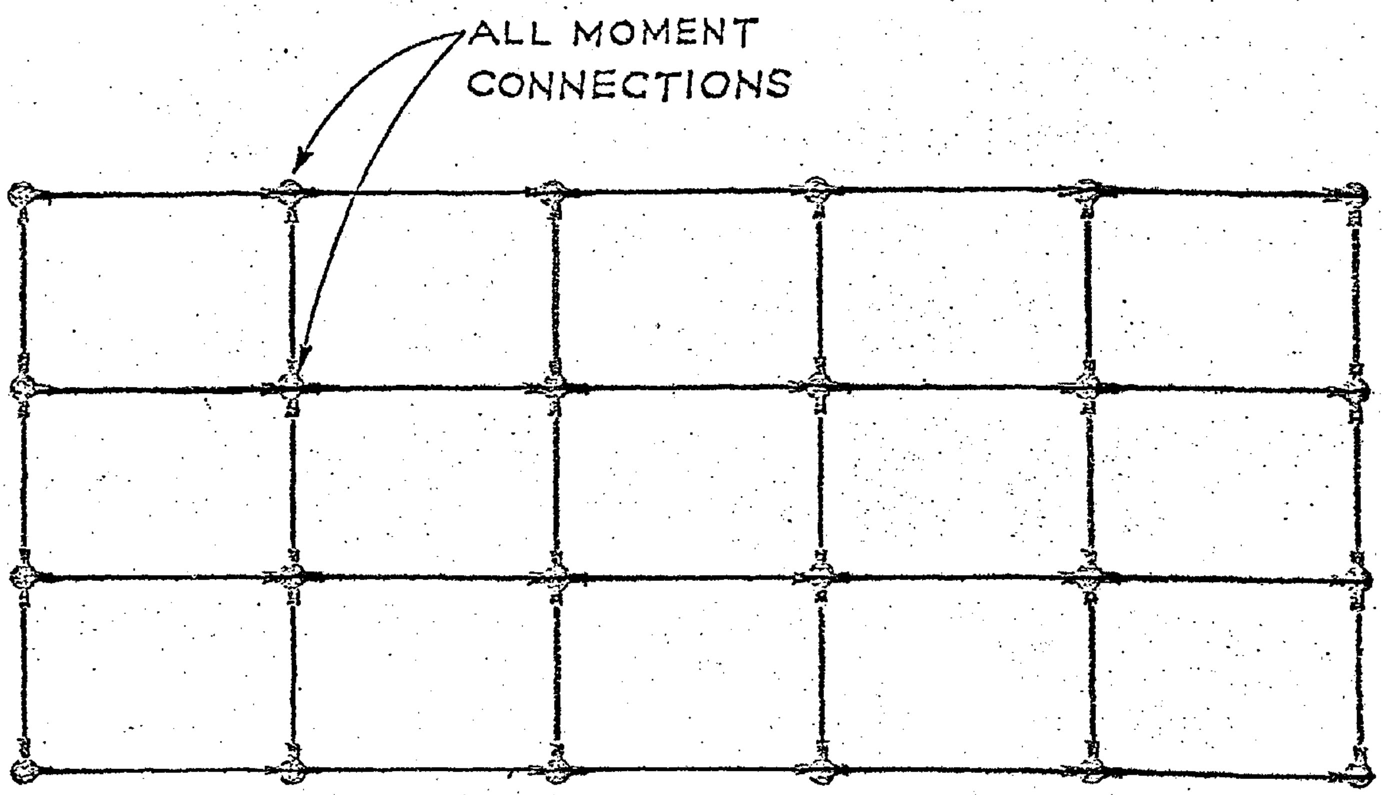
(c) COMBINATION FRAME
AND SHEAR WALL
K = 0.80



(d) STAGGERED TRUSS
OR STAGGERED WALL BEAM
K = 1.33

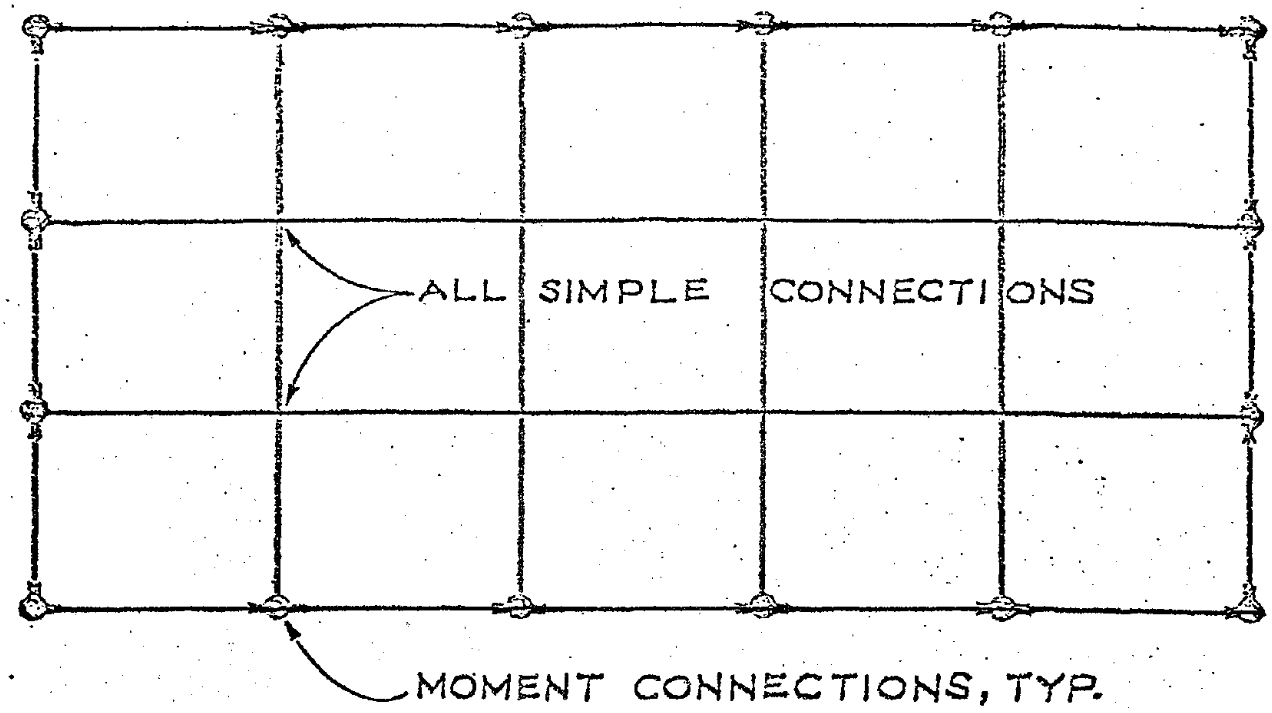
TYPES OF FRAMING

FIGURE 24

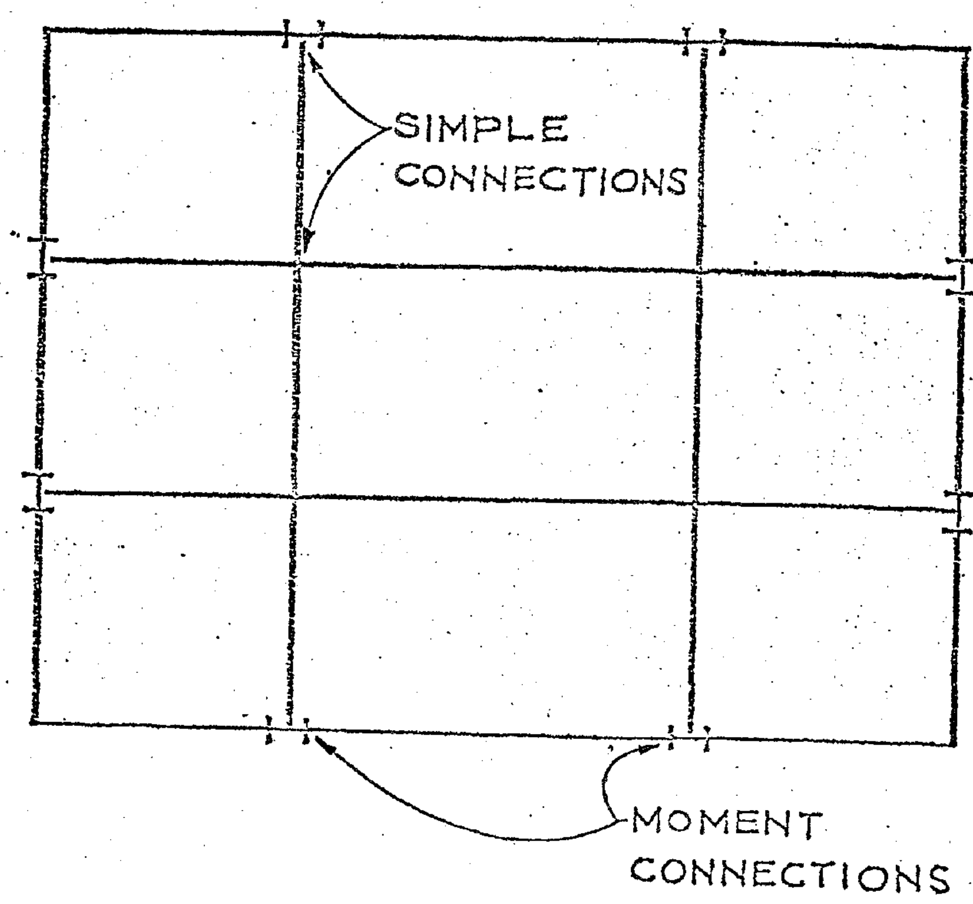


PLAN OF TYPICAL BUILDING
K = 0.67

FIGURE 25



(a)



(b)

PLAN OF TYPICAL BUILDING
K = 0.67

FIGURE 26

when this system is tested by the next major earthquake. We are not encouraged by the obvious and known deficiencies in joint design in concrete structures nor the problems encountered with welding of thick steels and the subsequent brittle fracture that has been observed in heavy moment connections.

SHEAR WALL

Returning now to Figure 24, the next framing method to consider is the all shear wall or all braced frame building. Shear walls come in all proportions and variations and their action may be completely different as compared to other types. They are limited to 160 feet in height and require a K value of 1.33 - twice that of the all moment resisting frame. All have been considered in the same class as the old Type III box system which performed so poorly in past earthquakes.

Some of the various types of shear walls are shown in Figure 27. First there is the high, narrow shear wall that resists forces primarily as a cantilever as shown in (a). This is really an inverted pendulum and is subject to all of the deficiencies of that type of construction. While it is the popular shear wall structure which many research workers consider to be the shear wall system, its primary force resisting system belies the name shear wall since the primary ultimate stresses are due to moment and not shear. There is no reserve system and its performance is more typical of water tanks or one-story umbrella structures with a heavy mass at the top. Consequently, a more appropriate "K" value would be 2 or 3 rather than 1.33. The past performance of this type of structure has been very bad as illustrated by the Four Seasons Apartment Building in Anchorage.

The second type of shear wall to be considered is the wall with heavy spandrels and small piers. The primary deficiency of this style of framing is the weakness of the columns as shown by the performance of several schools in Japan such as the Hakodate College in the 1968 Tokachi-oki earthquake. In that earthquake about ten 3 and 4 story school buildings failed although design requirements were generally in excess of the requirements of our codes or of Title 21. It is interesting to note that failure always occurred in the longitudinal direction where columns resisted the lateral loads in bending and not in the transverse direction where lateral loads were resisted by solid shear wall between classrooms. Much research has been conducted in Japan following that earthquake and has been reported in Reference 5.

The third type of shear wall is indicated in Figure 27 and consists of heavy piers combined with small spandrels. A whole new set of problems is introduced in this type of construction. First, the usual approximate methods of lateral analysis - such as the portal method - are invalid because of the great foundation to pier rigidity as compared to the spandrel rigidity. It is not uncommon with this ratio of stiffnesses to have the lowest column point of inflection 4,5 or more stories above the foundation as shown in Figure 28. Consequently, the column stresses are much greater than most approximate analyses would indicate.

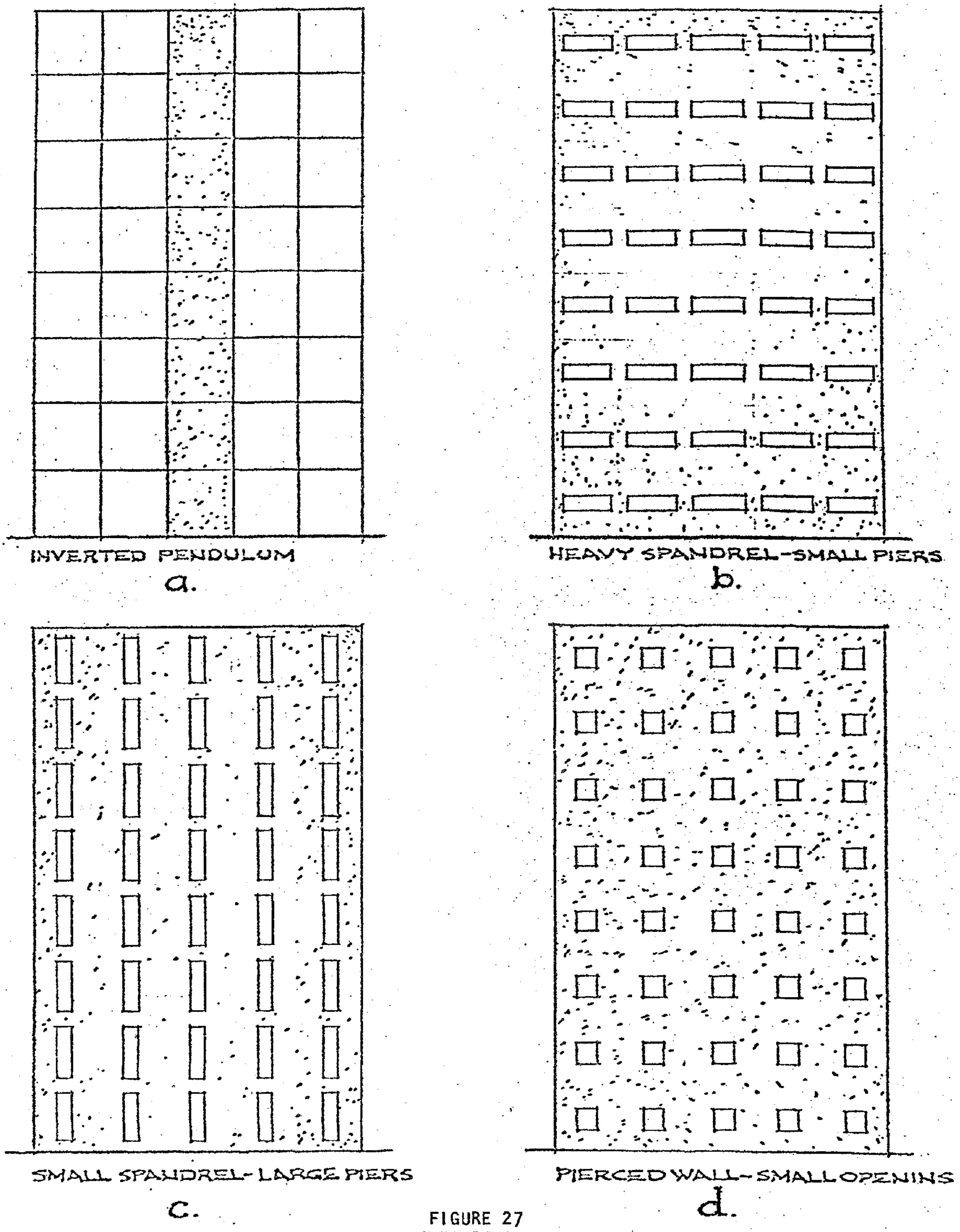

INVERTED PENDULUM
a.
HEAVY SPANDREL-SMALL PIERS
b.
SMALL SPANDREL-LARGE PIERS
c.
PIERCED WALL-SMALL OPENINS
d.

FIGURE 27

Another factor is our lack of knowledge concerning the performance of the spandrels.

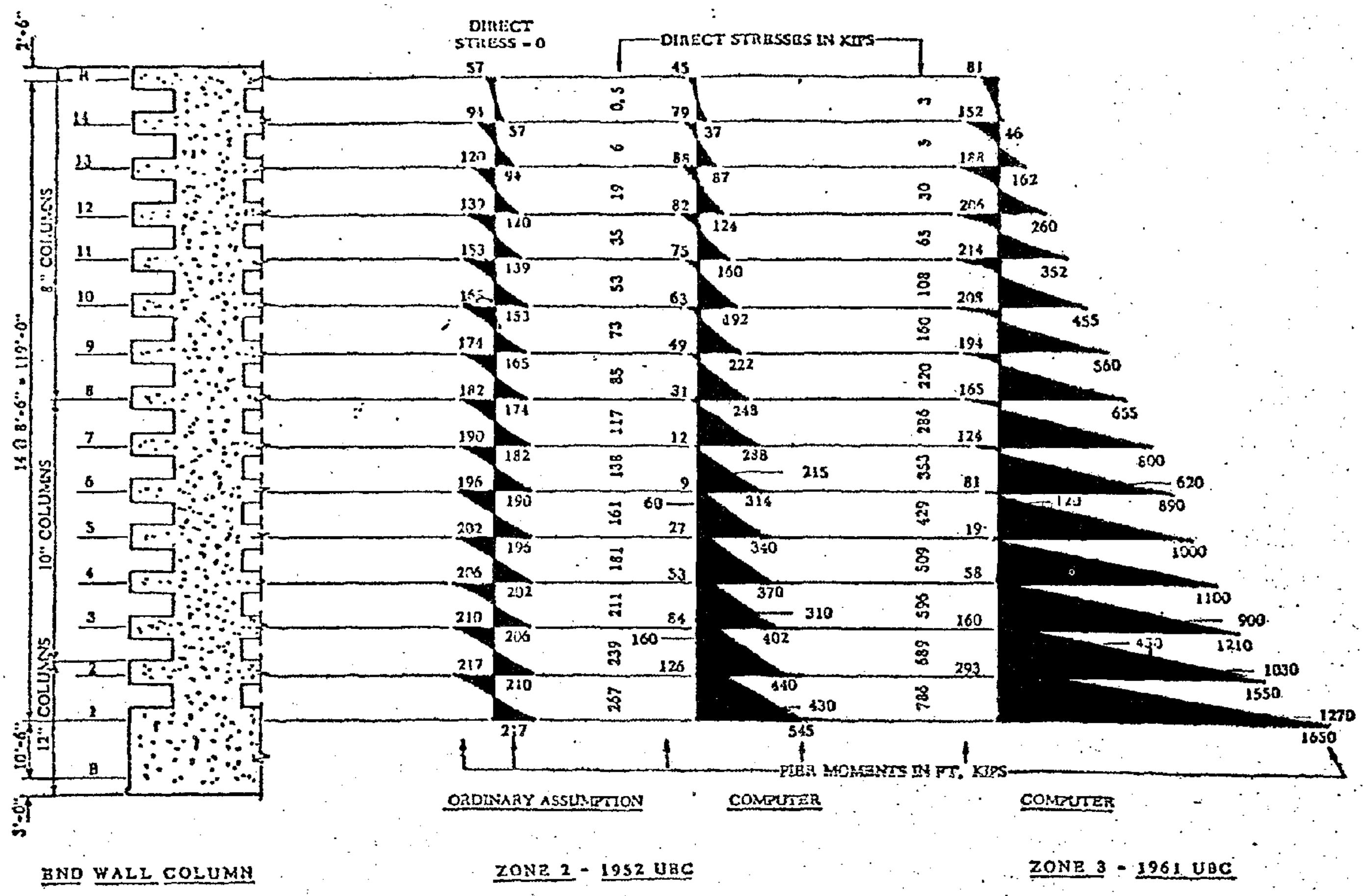
Some of our concepts about member deformations have been found to be erroneous. For example, consider the coupled shear wall element shown in Figure 29. Ordinary analysis considers a point of inflection in the center of the spandrel or girder with the steel stress varying for zero at the center of the girder to a maximum at the pilaster as shown in (b) and (c). Our calculated stiffnesses, strengths, shear resistances, etc. are based on this assumption.

Our concepts about shear and the allowable stresses are determined from deep girder theory, as shown in Figure 30. This is based on the assumption that a simple beam is similar to back-to-back cantilevers. And our basic concept of spandrel action with a point of inflection at the center consists of two anti-symmetrical cantilevers joined together for shear at the point of inflection.

Paulay[7] has found by testing that this is not true. In Figure 31, for the direction of load shown in (a) the steel stress varies from a substantial amount at "A" to a maximum at "B" as if the girder were really two triangular girders as shown in (d) with two points of inflection. Reversing the loads as in (b), also puts all the chord steel in tension as if there were two triangular girders as in (c). When the steel is stressed into the ductile range and is stretched, it elongates for <u>both</u> directions of loading, forcing the vertical piers apart and causing cracks to grow larger. In other words, the stresses are not reversible for reversible loading conditions. Similar conditions are found in some steel braced frames, for example, when rods elongate but do not compress or struts shorten and do not lengthen. With all its uncertainties, however, this style of shear wall structure has never collapsed in an earthquake although it has been severely damaged.

The fourth style of shear wall structure, as indicated in Figure 27, is essentially solid wall that is either solid or is pierced with relatively small openings. Traditionally, this has been a very safe structure when properly designed, but little is known about the analysis of the heavy short members. The spandrels are certainly subject to the same stresses and deformations discussed earlier. The joint design must be somewhat similar to that connecting longer slimmer members but is usually neglected by designers. The basic principles of such design, as far as they are presently known, are given in Reference 8.

Within the four general types of high-rise shear wall structures, there are an infinite number of gradations, variations and combinations. Since each general type has its own distinct problems and since each type has unique critical points, it is difficult to set up design standards that will provide equivalent performance. And yet, according to all codes and specifications they are treated equally as "shear wall structures". Unfortunately, most research workers dealing with shear walls also treat them as a single entity and do not differentiate in their studies just which type they are discussing. As a matter of fact, I doubt that more than a few even realize the diversity of the product they call "shear wall" and they certainly do not know of the immense differences in action or performance.



—Direct stresses and moments in the large, end-wall column under three different analyses. Plotted moments are at member centerline. Intermediate moments at the third and sixth floors in the computer analyses are at the top and bottom of the spandrels.

FIGURE 28

(TAKEN FROM REFERENCE 6)

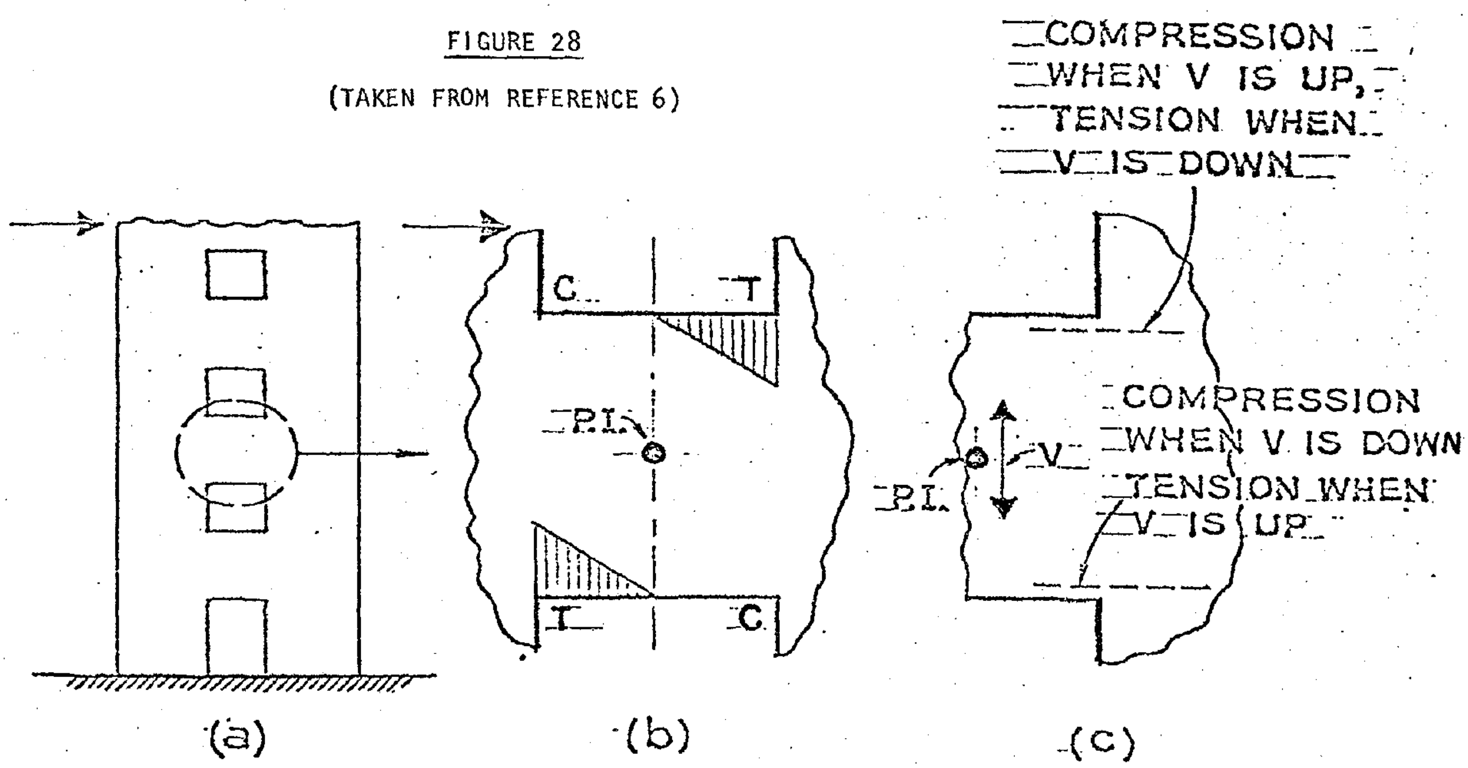


FIGURE 29

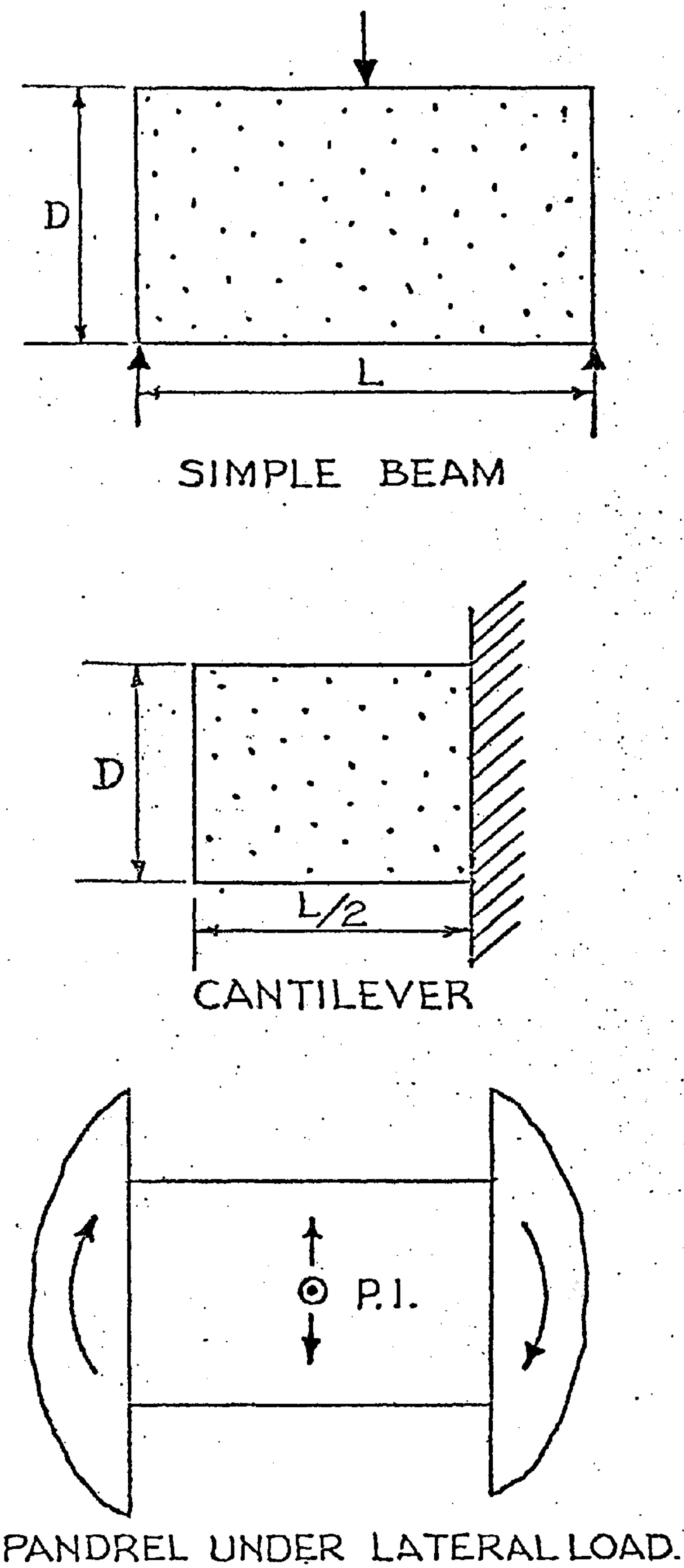

D
L
SIMPLE BEAM
D
L/2
CANTILEVER
P.I.
SPANDREL UNDER LATERAL LOAD.

FIGURE 30

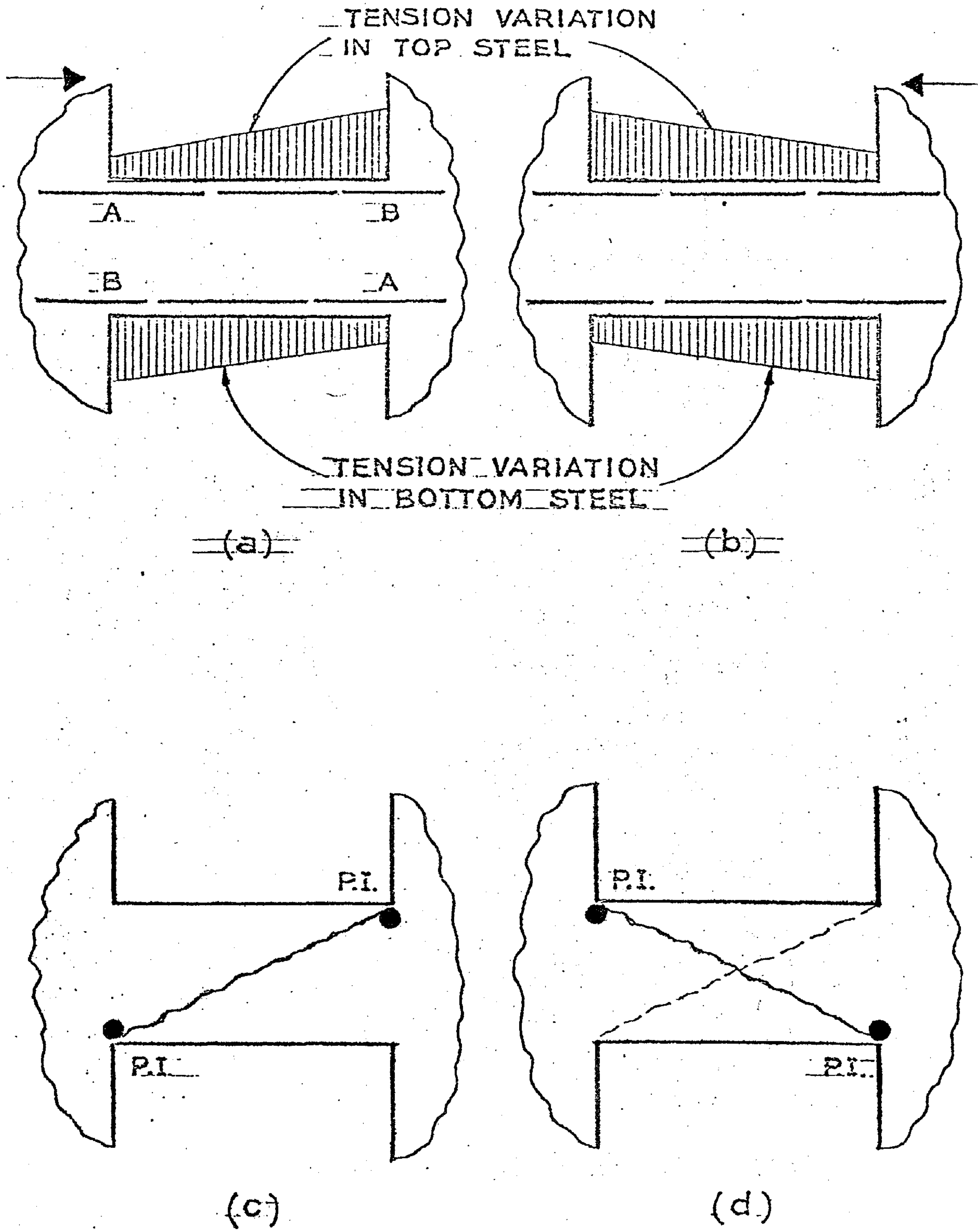

TENSION VARIATION
IN TOP STEEL
A
B
B
A
TENSION VARIATION
IN BOTTOM STEEL
(a)
(b)
P.I.
P.I.
P.I.
P.I.
(c)
(d)

FIGURE 31

As to perfomance, the inverted pendulum Figure 27 and the small pier Figure 27 types have failed miserably in past earthquakes, while the other two types have been damaged severely but have not collapsed.

COMBINATION FRAME/SHEAR WALL

Returning now to Figure 24 showing the various general types of framing of high-rise structures, let us consider the combination frame and shear wall as illustrated in (c). This structure rates a K=9.80 in present codes. Shear walls - with all of the diversity indicated earlier, may be on the exterior, around the core or elsewhere in the interior or any combination.

The early reputation of steel high-rise construction to resist earthquakes was earned by the older style frame construction with brick or masonry or later poured concrete walls. Many of these structures had stiff walls that would crack and break up in a major earthquake, absorbing energy and providing much needed damping and stability for the rather light but very ductile steel frame. They did not collapse and usually were rather readily repaired when damaged. With the advent of the curtain wall in the 1940 era, the necessity of the heavy masonry exterior wall disappeared and with the development of the dry two-hour fire wall for elevator and shaft vertical openings between floors, the necessity for heavy masonry walls on the interior was eliminated. Lightweight materials - sometimes prefabricated - resulted in less load on the structure and consequently more economy. As a result, the all-moment frame building with a K=0.67 became fashionable and is used almost exclusively now. As discussed later under "drift", in those cases where it has been shaken by strong earthquakes, the performance has not been good.

Before the K=0.67 building was used extensively, and after unreinforced masonry suffered from the major failures in the 1933 Long Beach earthquake, most of the medium height to tall buildings used steel frames with reinforced concrete substituting for the masonry. These buildings were similar to but much stronger than the older tested construction, in that the concrete, like masonry, could still crack and absorb energy while the steel frame was held in reserve. This was and is the system illustrated in Figure 24 - a combination system. Whenever we speak of shear walls, braced walls are considered the equivalent. In this system, there are three conditions of design that must be met. First the combined, composite structure must resist the design loads in accordance with their relative rigidities. Secondly, the shear walls acting alone must resist the entire lateral force. The columns and beams can act as reinforcing and must still take vertical forces. Third, the ductile frame alone - without the concrete or the braces must take not less than 25% of the required lateral force.

The design of the shear wall elements is the same as previously discussed for all shear wall buildings. Certain items such as spandrel shears, overturning, etc., are of great importance. The ductile frame requirements are the same as discussed for the all-moment frame structure except that the frame is designed for much lighter forces.

It is the strong belief of our office that this combination framing method is by far the safest method of resisting earthquake forces in high-rise construction. The shear walls stiffen the structure so that drift is not a problem. Motions from wind and moderate earthquakes are much smaller with less consequent architectural and equipment damage. And, when the large earthquake hits the structure, there is a proven system that is capable of absorbing great amounts of energy and still remain stable. When damage does occur, it should be easier to repair. With all of this, the frame is lighter. This system does have the disadvantage that it is more expensive for the engineer to design and detail, as there are three separate analyses to perform and large amounts of detail to be drafted where the frame interacts with the shear walls. We feel that when the concerned owner is aware of the problems and benefits of the combination system, he is also pleased with this choice of system. It is my belief that after the next large earthquake occurs in a major metropolitan area, the combination system will be almost mandatory. The property damage potential alone of the all-moment frame system is frightening as exemplified in the Santa Rosa 1969 earthquake, and the San Fernando and Managua earthquakes.

A pure shear wall design with random openings is very difficult to analyze. In the design office, the only present recourse is to analyze it with points of inflection of logical points, some general assumptions as to relative rigidities and some rational determination to assure that static equilibrium is preserved. The only relatively rational method of analysis is with finite elements and that method is too expensive for most structures in the average engineering design office. One of the criteria to be aware of is to eliminate or reduce the effect of obvious weak areas.

For example, in many structures with typical floors, the shear wall is penetrated by openings at regular intervals. One example is the Anchorage Westward Hotel where doors to certain rooms always were located in certain typical locations. When considering the vertical overturning stresses (horizontal shear in a vertical plane), the spandrels over the doors must transfer the vertical shearing stresses from overturning. Since this is the weakest plane of the shear wall, the damage is located at this point on all floors. This same shear effect has been noted in many buildings in several earthquakes. The penetrations of the shear walls, whether they be doors, duct openings or other architectural features, are zones of weakness and must be treated accordingly.

STAGGERED TRUSS

The last framing system to be considered is the one illustrated in Figure 24. With steel frames, this is called the staggered truss system, and in concrete it is called the staggered wall beam system. This system promises considerable economics in high-rise apartment construction where modules can be staggered or offset from floor to floor. The primary lateral force system consists of the truss or beam transferring shears from one floor to another with the floor slab diaphragm carrying shears between trusses or beams, as shown in Figure 32. There are no primary bending stresses except at the corridor, as shown in Figure 33. Since there must be communication between walls or trusses at the corridor, a rectangular opening must be located at that point. This introduces a large hole in either the truss or the wall beam where vertical shears must be transferred across the opening, causing high bending and shearing stresses in addition to the high compression at the top of the truss or wall and high tensions at the bottom.

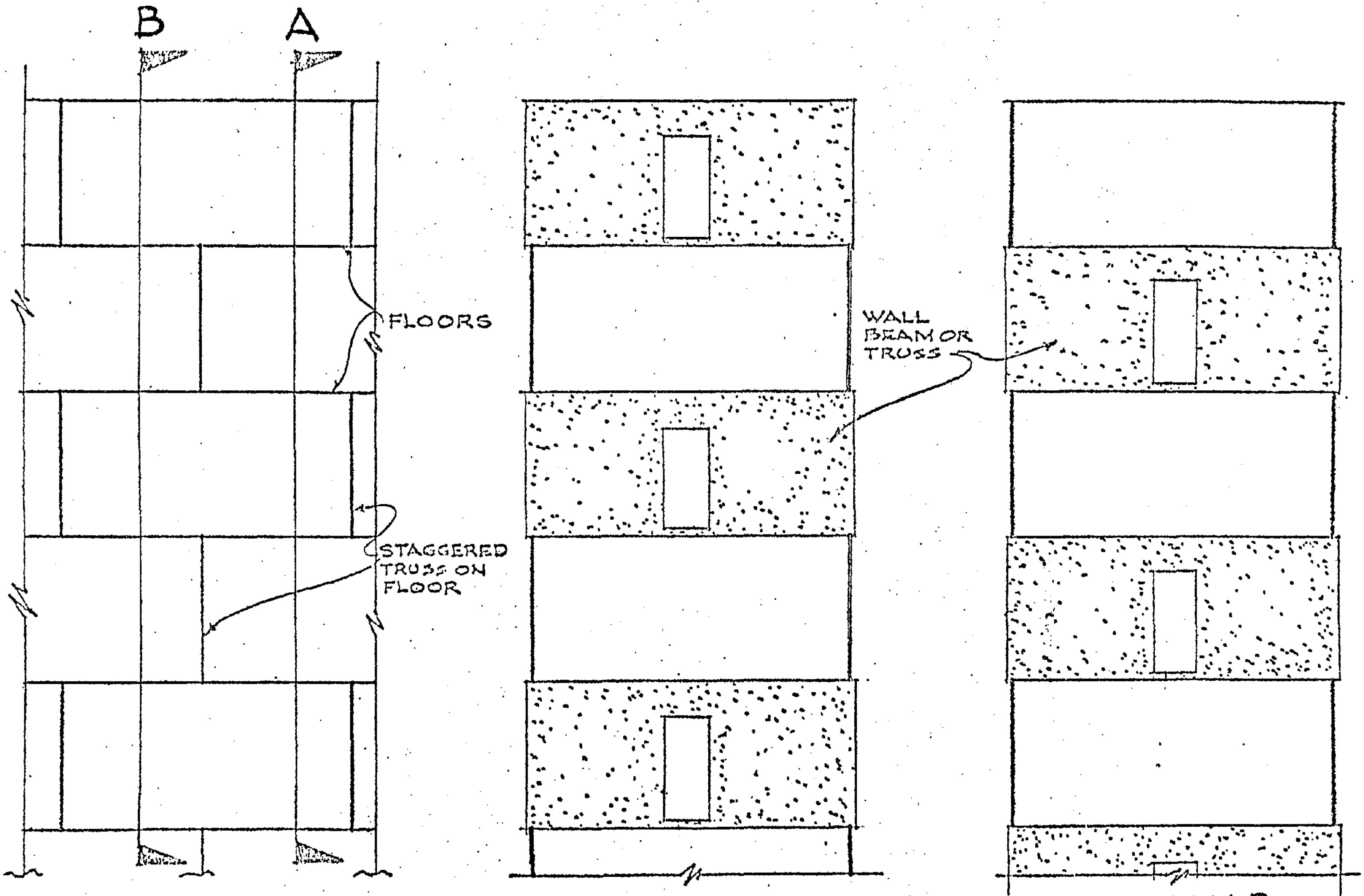
Most of the energy absorption of the whole system is concentrated at this single location and very high ductility ratios are required, according to recent research at the University of Michigan. One of the most overlooked points in this type of framing is the transfer of the entire transverse building shear through the floor diaphragm as shown in Figure 33. The building shears between floors A to B and C to D are transferred by trusses X, while the building shear from floor B to C is carried in truss Y. The floor diaphragm must transfer the shears from truss X to truss Y and back again. These shears can become very large.

In all of the framing schemes discussed above, it is of prime importance that a complete, logical continuous stress path is provided. This involves the proper design of joints and connections, the provision of adequate trim bars at openings, collector or drag reinforcing and substantial tieing together of various components of the building. Time does not allow proceeding further with these details that will ultimately have a greater effect on the performance of the structure than any sophisticated analysis. For those interested in pursuing the subject further, study references 5, 6, 8 and 9.

And, it is unfortunate that we do not have the time to proceed further in discussing these details or illustrating the problems. But for those who are newly involved in the design of structures to resist earthquakes, references 6, 8 and 9 should be reviewed and studied.

BUILDING CONFIGURATION

The next problem to be considered is the overall configuration of the building, both as seen in plan and as seen in any elevation. Here is where the architect has more influence on the future performance of his structure in an earthquake than anything his structural engineer can do. If we have a poor configuration to start with, all the engineer can do is to provide a band-aid -improve a basically poor solution as best he can. Conversely, if we start off with a good configuration and a reasonable framing scheme, even a poor engineer can't harm its ultimate performance too much. This last statement is only slightly exaggerated. Much of the problem would be solved if all structures were of a regular shape, but economics of lot sizes and arrangements, various planning requirements for efficient use of space, and esthetically pleasing proportions require the structural engineer to provide for safe constructions of various shapes. L, T, or U shapes or variations of these must be accommodated in many building designs as shown in Figure 34. Designers must realize that reentrant corners are areas of great stress and must reinforce their structure accordingly. In code terms, the amount of stress is difficult to define, therefore,



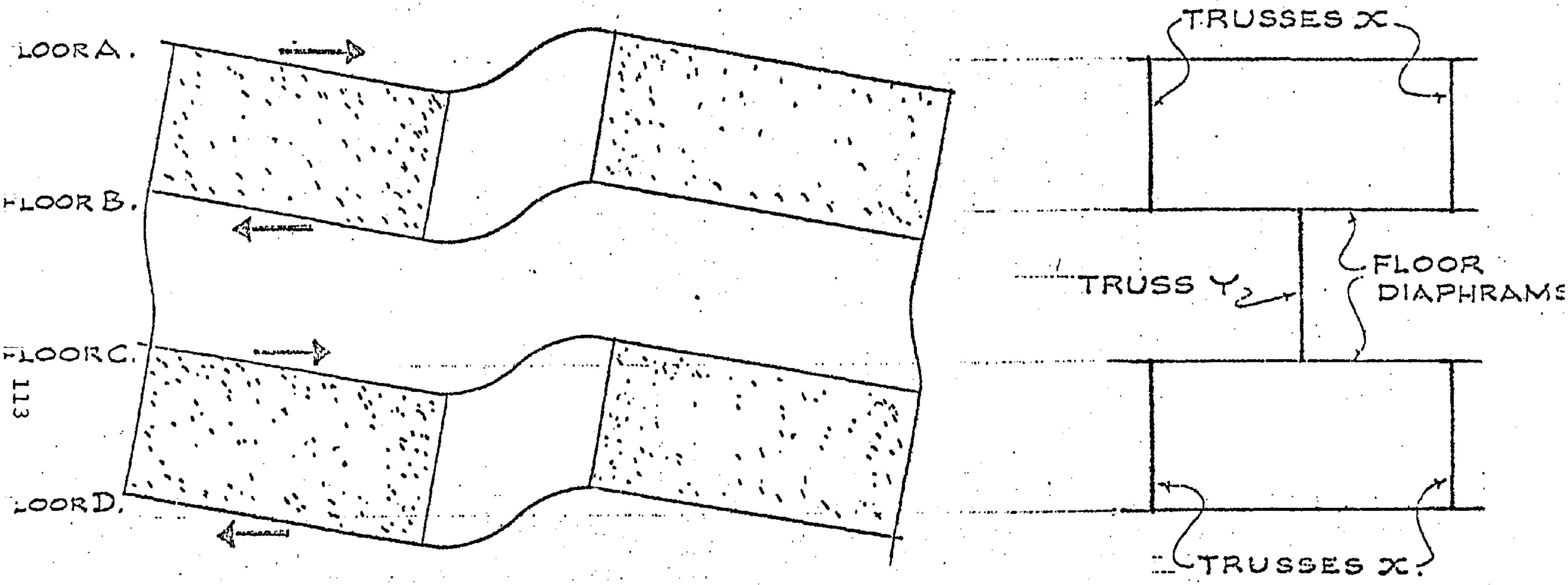
LONGITUDINAL SECTION THRU BUILDING.

SECTION A

SECTION B

TRANSVERSE SECTION THROUGH BUILDING

FIGURE 32


LOOR A.
FLOOR B.
FLOOR C.
LOOR D.
TRUSSES X
TRUSS Y
FLOOR DIAPHRAMS
TRUSSES X

a.

b.

FIGURE 33

each case must be individually analyzed by the engineer, considering the magnitude of forces to be resisted. Provisions must also be made to resist various combinations of force transference that are likely to occur.

TORSION

All buildings, no matter how regular theoretically, are subject to torsion and those non-symmetrical shapes will be subjected to major torsional stresses. A classic example is the building that has a cross shape in plan. By relative rigidities the long bents, marked A, in plan, will take most of the lateral loads while those marked B, which are comparatively short, take very little lateral load. For any tendency of the building to twist in plan because of earthquake torsion, unbalanced wind loads, or column buckling, it can be readily seen that bents A are relatively inefficient, due to the short moment arm, and much of this torsional load must be taken by bents B. Consequently, bents B will probably have to be designed for more load than would be anticipated from relative bent rigidities, if torsion is neglected. Many engineers try to solve this problem by introducing earthquake joints at various locations. This solution not only involves such architectural problems as appearance, watertightness and damage to utilities crossing the joint, but almost insures that there will be pounding of the structure adjacent to the joint in the event of an earthquake.

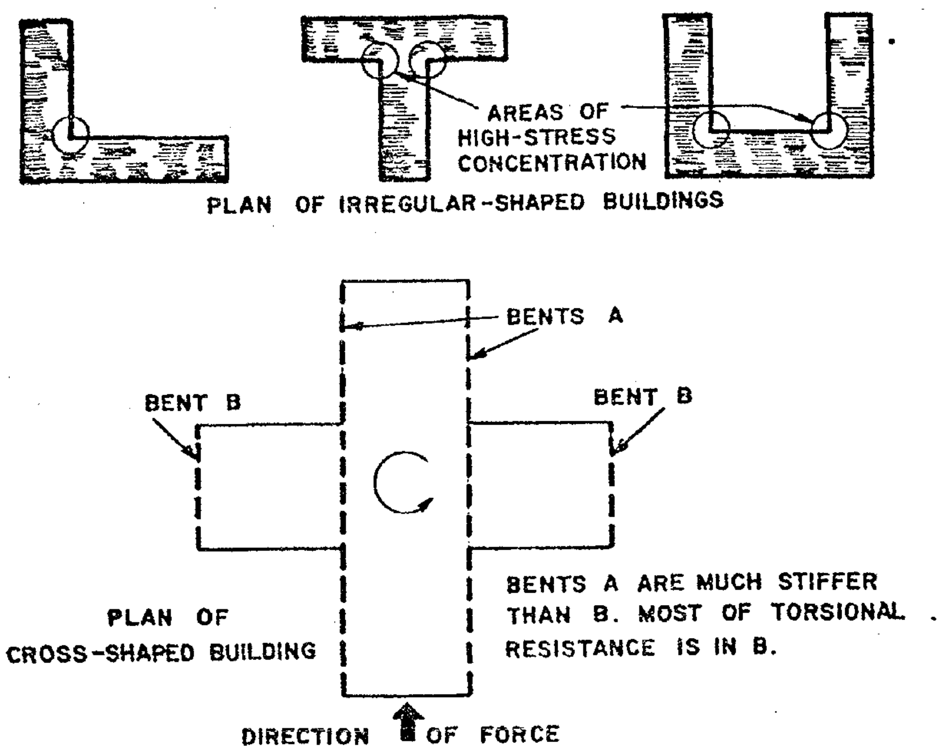


FIGURE 34

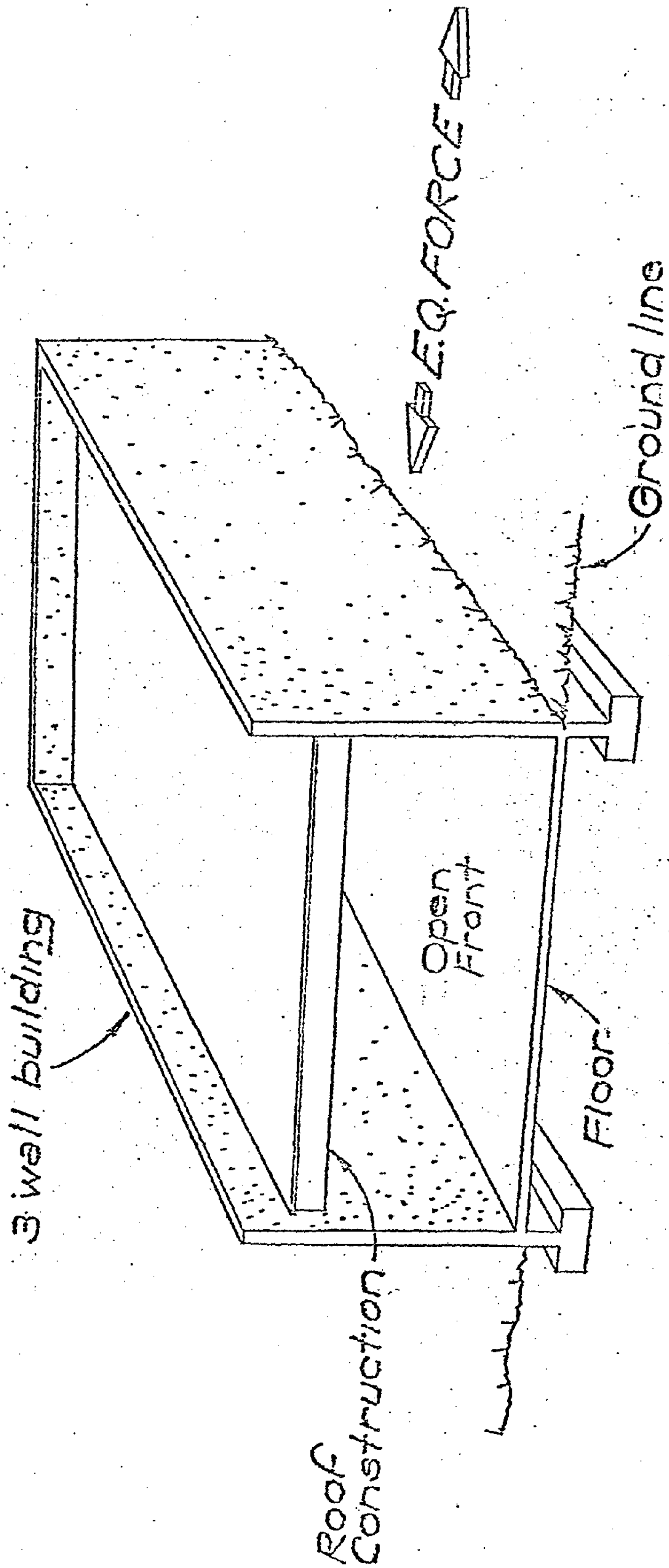
The effect of torsion can probably be best illustrated by one of the most common building constructions in the United States if not the world. Figure 35 shows a typical 50 foot by 100 foot (or other dimension) open front commercial building. The side walls are on property lines, the rear wall is either on a property line or faces an alley. Since the side walls are on property lines, there are no openings. The rear wall has minimum openings, if any, but the front wall with its display windows on the street is essentially open. When shaken by an earthquake, the rear and side walls are quite rigid but the front wall is very flexible, and the roof tends to twist. There have been some studies indicating that any columns in the front wall will be highly stressed in torsional shear in addition to the normal deflection loads and shears. The movement of the building is shown in Figure 36. While the best solution is to make the front wall as stiff as the rear wall to eliminate the torsion, this is often impossible. The only compromise solution, therefore, is to stiffen up the front wall as much as possible as shown in Figure 37, to reduce the torsional movement as much as possible.

Figure 38 shows the plans of three similar buildings, each with three shear walls so arrranged that there is an open end and therefore major torsions on the buildings. If the buildings are similar, with uniform shear elements (uniform distribution of stiffness) and considering only shear deformations, it can rather simply be proved that the torsional deflection of the open end varies as the <u>square</u> of the length of the building. For example, in Figure 38, if Building A has a torsional deflection of 1 inch at the open end, Building B will have have 4 inches and Building C will have 16 inches of deflection. It is probable, but not proven, that buildings with a ratio of L/D equal to or about 1/2 or less should have little trouble due to torsion in an earthquake, since the total deflections including torsion will be about the same as the symmetrical loading of the earthquake in the perpendicular direction. With ratios of L/D above 1/2, the torsional deflections including torsion will be about the same as the symmetrical loading of the earthquake in the perpendicular direction. With ratios of L/D above 1/2, the torsional deflections increase rapidly and damage will surely occur at the open end, unless specific precautions are taken.

Because of the great uncertainties it is better, if at all possible, to reshape the structure into a more regular and balanced structure. While the odd shape may be justified on economic and utility bases for many structures, leaving it up to the structural engineer to do the best he can, it should be avoided in any way possible in critical structures such as hospitals.

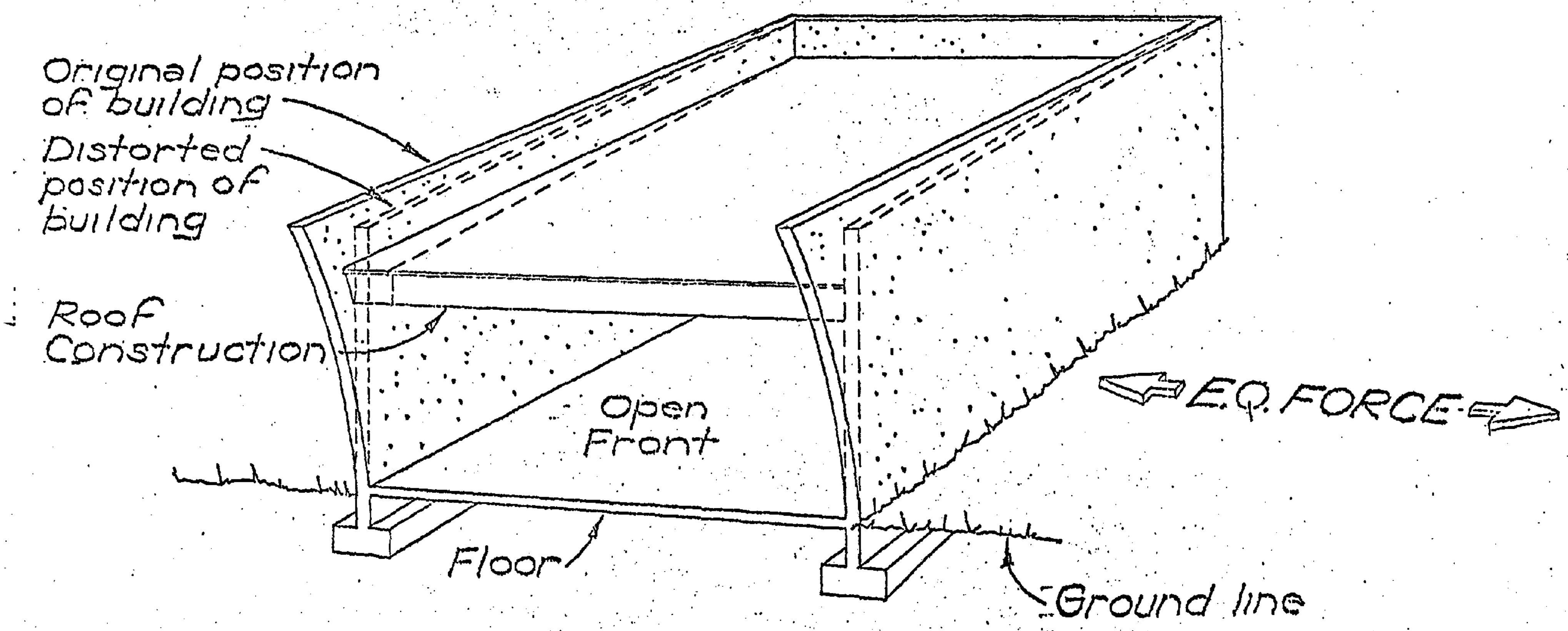
UNIFORMITY OF MASS, STRENGTH, STIFFNESS

The other important element of configuration is the provision of a uniform distribution of mass, strength and stiffness throughout the height of the structure. The classical example of a violation of this principal has been the flexible first story, but there are various other similar conditions. The provisions of the code forces, assuming various material ductilities has always been for the "average" building where the strength, stiffness and mass has been reasonably uniform throughout the height of the structure. The energy absorption has been



AS CONSTRUCTED

FIGURE 35



PROBLEM

FIGURE 36

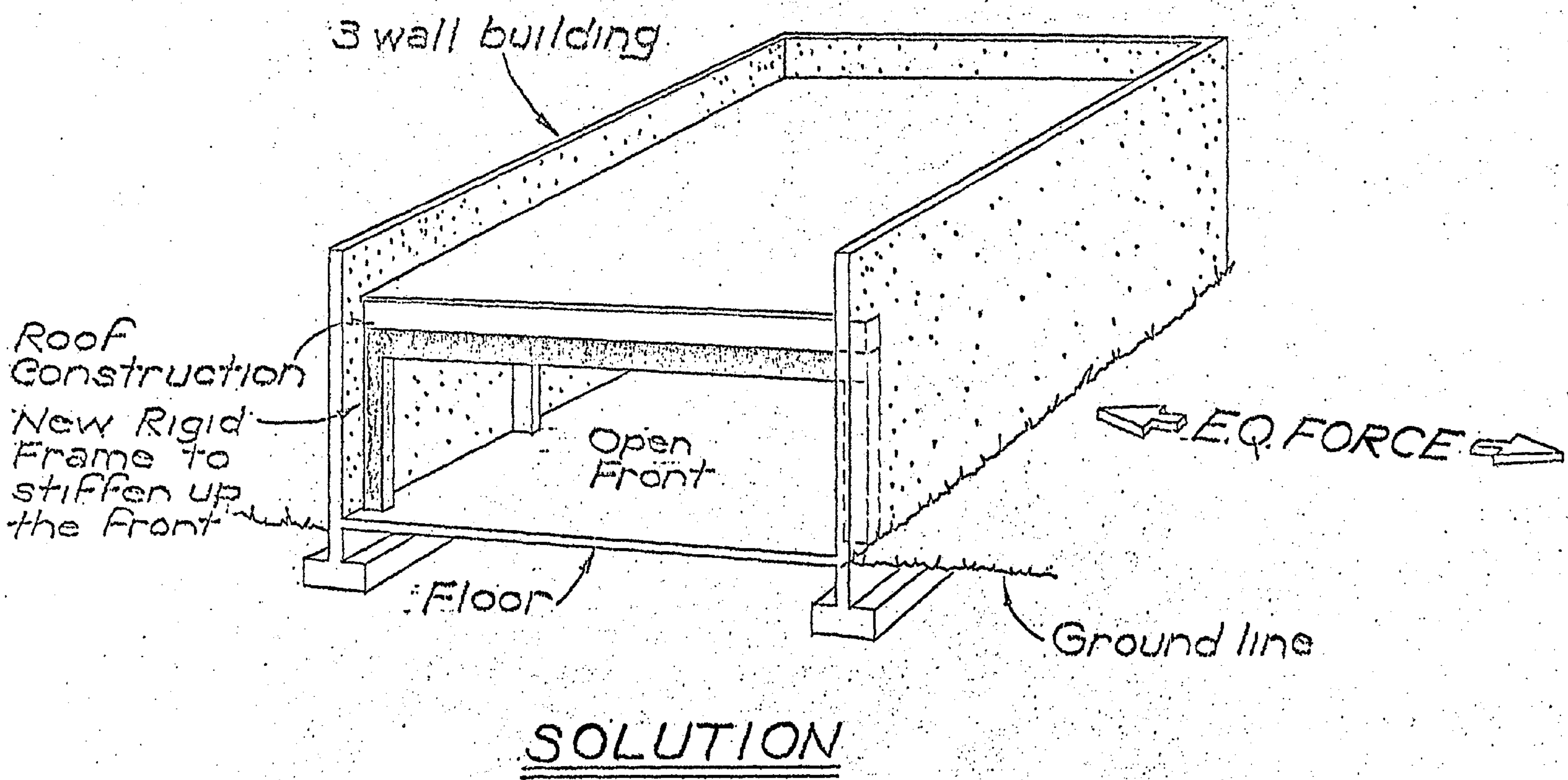
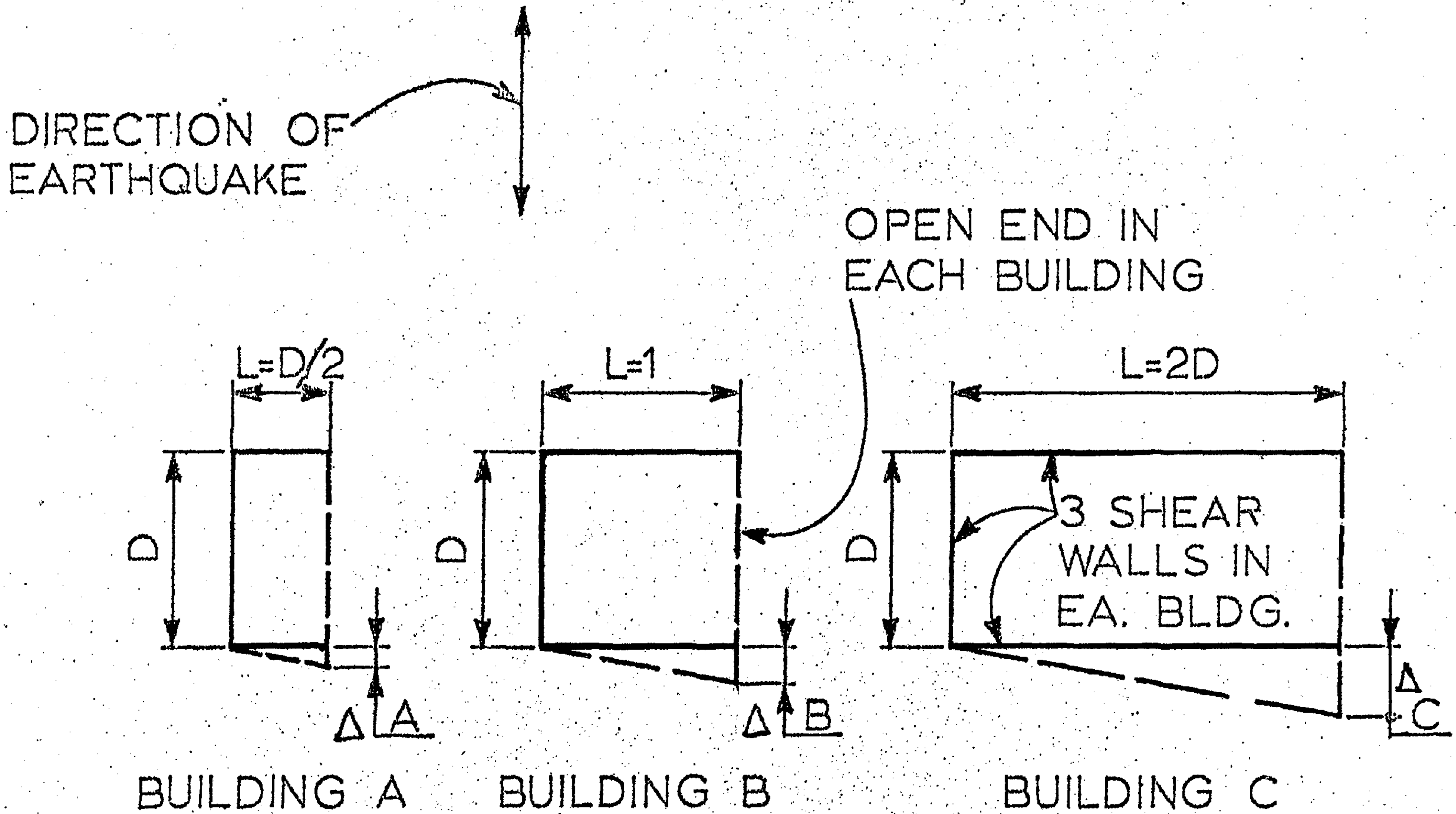

3 wall building
Roof Construction
New Rigid Frame to stiffen up the Front
Open Front
EQ FORCE
Floor
Ground line
SOLUTION

FIGURE 37



BUILDING PLANS

FIGURE 38

assumed to be distributed throughout the height of the structure and not concentrated in a single place.

We usually think that a modal analysis will account for these stiffness variation effects, but since it is based on elastic response it does not fully account for these discontinuities. Calculations are based on an elastic structure, and the performance of the structure as predicted by current analyses is reasonably correct until plastic action begins. When the plastic hinges form, the energy demand is concentrated more at the weak region. If other portions of the structure have greatly different properties, the modal analysis does not fully account for the excessive plastic deformation that occurs in one concentrated location as compared to the elastic deformations occurring elsewhere.

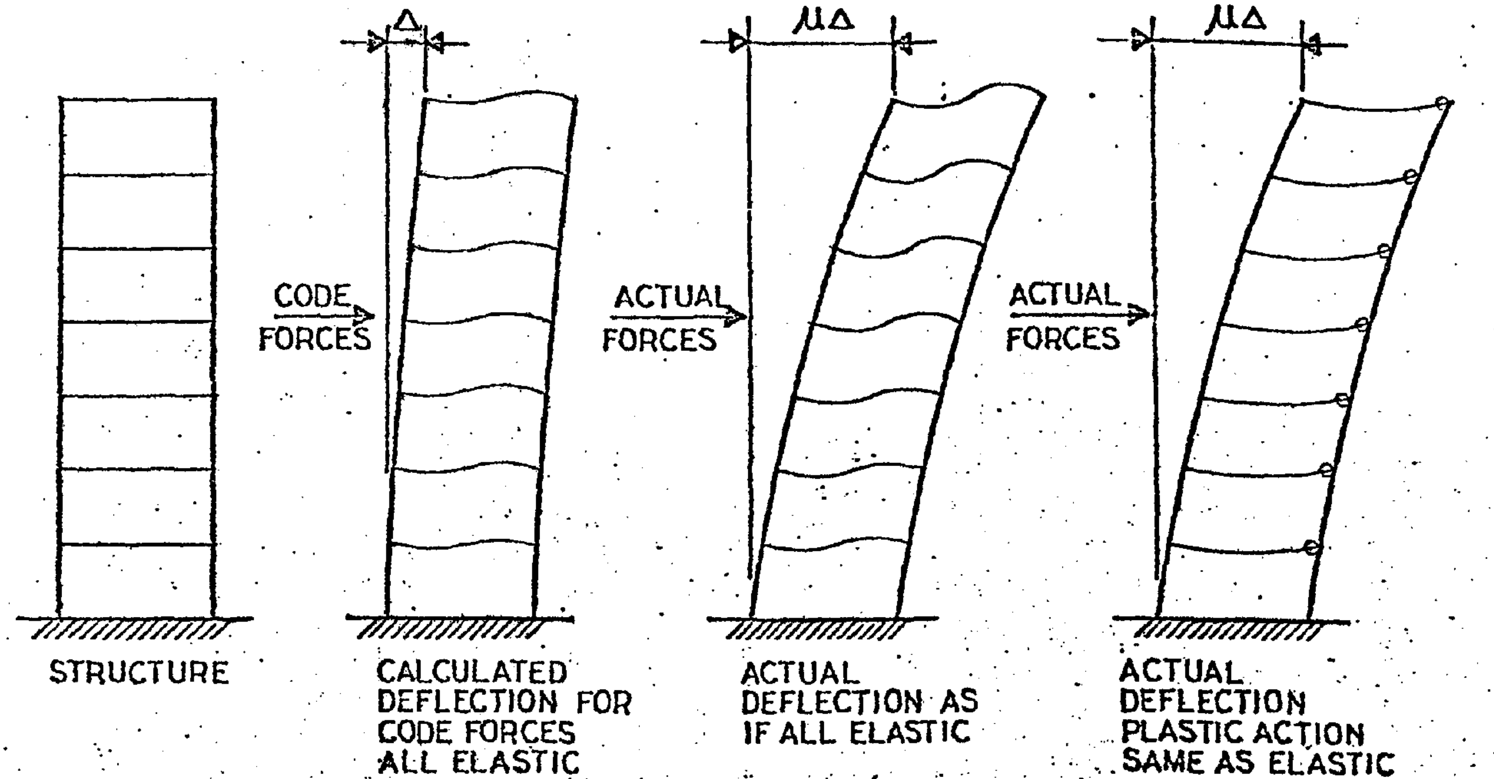
We earlier discussed (Figure 9) the method of reducing code forces as compared to actual forces or deformations by the use of ductility. Strictly, this is only true for a single mass system. It has been assumed to apply to multistory buildings if certain criteria are met as noted above.

As an example, consider the seven story structure shown in Figure 39. If we consider the average structure in the top portion of the figure where the mass, stiffness and strength are well distributed along the height, the code forces will indicate a deflection at the top equal to Δ . But we know that the actual forces are greater by the ductility factor and from the principles illustrated in Figure 9, the actual deflection will be the ductility factor times Δ (point B instead of point A in Figure 9). If the properties of the structure are uniformly distributed throughout the height, this increase in deflection is more or less uniform, permitted by the hinging of the girders (or columns) throughout the height.

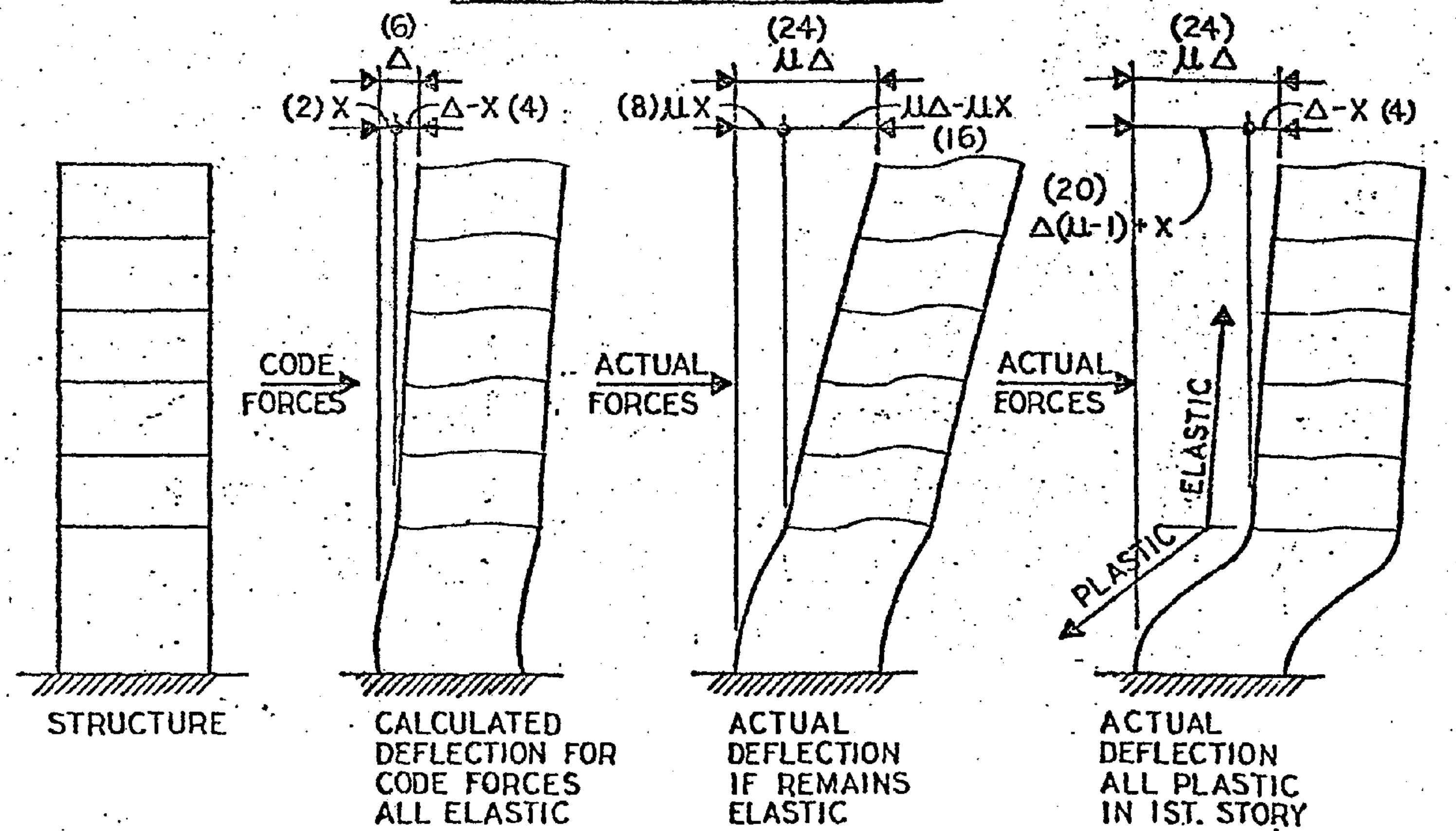
Now if we consider a similar structure with a "soft" first story as shown in the lower portion of the figure, the code forces will give an elastic deflection as shown at the left. This is made up of the elastic deflection of the first story "X" plus the deflections from the rest of the structure Δ -X. The actual earthquake forces will again cause the total structure to deflect by the amount of ductility times Δ as indicated in the center bottom. But if the structure above the first story is so stiff and so strong as compared to the first story that the first story must absorb all of this excess deflection in the plastic range and the top remains elastic, it can be seen that the first story is deflected much more than our elastic analysis would indicate.

This same principle would apply to any other point of discontinuity along the height of the structure. Earthquake damage experience has confirmed the danger of these discontinuities of the structure.

One suggested solution - not adopted by any code authorities is shown in Figure 40.



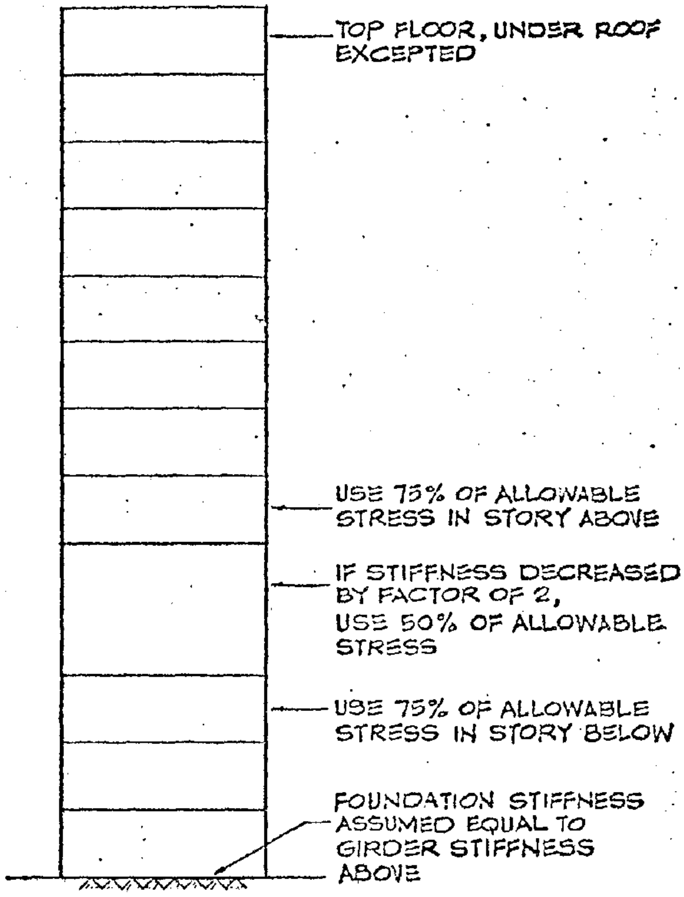
AVERAGE STRUCTURE



SOFT FIRST STORY

ASSUMED $X = 2$, $\Delta = 6$, $\mu = 4$

FIGURE 39



DISCONTINUITY EFFECT

FIGURE 40

An illustration of what occurs structurally at a weak or soft story occurs above the first floor was found in the recent Guatemala earthquake. The fourth floor of the Terminal Hotel failed because it has less lateral resistance that the floors above and below. But here the reason was not a change in the structure, but the absence of tile non-structural partitions on the fourth floor to accommodate some meeting rooms. The floors above and below had tile partitions that provided actual if not calculated strength. Too much strength on those floors as compared to the weak floor forced most of the deformation into one place with consequent failure. The architect must be aware of this possible result of his placement and use of non-structural elements.

A similar situation has occurred in many other earthquakes in one story schools or other buildings where the shady side of the building has tall windows and the sunny side has high windows set in "non-structural" walls. The support that these walls give to the columns in the load direction parallel to the wall makes these columns much stiffer so that they take all of the logitudinal earthquake load rather than only half of it. These columns often fail in shear. Because the architectural elements made the building stronger but put the stiffness in the wrong place, failures occurred. There are many other locations in buildings where the unwanted extra strength furnished by non-structural or architectural elements in the wrong places can cause serious damage if not failure. Examples could be non-calculated walls around stairs, elevators or duct shafts, as well as exterior walls, stiffened columns due to stair connections or canopies, non-uniform loadings or layout, or introduction of utility or mechanical features in various places.

LATERAL DEFLECTION

As a final point, I would like to mention lateral deflections or drift. Excessive deflection causes problems in glass, partitions, curtain walls and in other ways even without an earthquake. Under earthquake conditions, a flexible building permits an excessive amount of damage to the architectural, mechanical and electrical components as well as the building contents. Structurally, especially in tall buildings, excessive deflections can create excessive secondary stresses such as the P-Δ effect. For this reason, some engineering offices including our own, try to make our structures reasonably stiff as well as tough and ductile.

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SEISMIC DESIGN : ARCHITECTURAL SYSTEMS AND COMPONENTS

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CONTENTS

SEISMIC DESIGN : ARCHITECTURAL SYSTEMS AND COMPONENTS

INTRODUCTION

Man has made great achievements in science, medicine and engineering during the past two thousand years, however his knowledge of the cause and influence of earthquakes on structures and non-structural systems has not kept pace with those advances, and as a result there has been a great loss of life and damage to property.

The subject of seismic design is not a simple clearcut technical issue. It is highly complex with many building options and it also embraces social, economic, moral and political issues. This paper only deals with a facet which is architectural systems and components and their expected reaction with varying structural systems and seismic design planning in the future.

For the purpose of this paper we shall define the following:

Architectural Components: Materials which are used in architectural systems. They shall include but not be limited to the following materials: unit masonry, preformed siding lath and plaster, glass and glazing acoustical material gypsum board, veneers, precast concrete.

Architectural Systems: Systems shall include occupancy groups, stairs, public and private corridors, exits, exterior and interior wall assemblies, ceilings, canopies, roof units, containerized elements (planters) equipment furniture and artwork, doors, seismic joints.

BUILDING CODES

One of the earliest building codes in the United States containing seismic provisions for architectural components was the Uniform Building Code of the Pacific Coast Building Officials Conference (presently known as the International Conference of Building Officials). The 1927 edition contained an appendix on earthquake provisions which could be adopted by the local authority at their option.

The first mandatory seismic code was published in 1933 following the March 10, 1933 Long Beach earthquake. Shortly thereafter the State of California legislators passed the Field Act, which required design and construction requirements to be controlled by the state's Division of Architecture. Under influence of the Structural Engineers Association of California (SEAOC) and the State of California, seismic design and construction supervision requirements have been a factor in our present day building requirements.

The Riley Act became effective on May 26, 1933. This act increased the scope of seismic and wind protection requirements. Since these early days of earthquake code development there has been modification to existing model building codes which usually occurred after each major earthquake, however very little has been done to improve the perfor-

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mance of the architectural components. This is understandable when you consider that the structural engineer is active in seismic codes and little attention is given by the practicing architect. Most local government jurisdictions in California have adopted the Uniform Building Code (UBC). The earthquake provisions of the Uniform Building Code are based mainly on the recommendations of the Structural Engineers Association of California. The Uniform Building Code has provided the leadership for all other model building codes.

The UBC establishes minimum requirements for nonstructural components (1976 edition) including walls, partitions, parapets, suspended ceilings and exterior-interior ornamentations and appendages.

In recent years a basic philosophy of design for seismic resistance was formulated to provide a rationale for the provisions of codes. This concept holds that, in a moderate quake the building should continue in service with the probability of light nonstructural damage, but no structural damage. In the event of a very strong quake the building should not collapse or be hazardous to the occupants although considerable amount of nonstructural damage and some structural damage might be expected.

SEISMIC DESIGN CONCEPTS

INTEGRATION OF BUILDING SYSTEMS AND COMPONENTS

Nearly all buildings are a combination of flexible and still components. The improper combinations of such elements may create problems in building performance under earthquake loading. This improper combination of elements may result in designs that not only have highly variable behavior in earthquakes, but also effect the structural system of the building. A classic example of this condition is the use of masonry wall infill between a moment resisting frame members when the wall is not designed as a component of the frame. Since most of these problems derive from basic architectural decisions as to the plan and form of the building, it is extremely important for the architect to understand them.

Nonstructural components must be properly integrated with or effectively isolated from the basic structural frame if excessive damage and loss of life is to be avoided.

(1) The deformation approach where the components are designed with the ability to absorb stress through elastic response

(2) The detached approach where the components are free from movement and avoid direct stresses.

The interaction between nonstructural components and structural systems can be divided into two basic relationships. These relationships are the effect of the nonstructural components on the structural system and the structural system effect on components.

(1) The effect of most nonstructural components on the performance of the structure in most cases is neutral, however in certain cases significant modifications to the structural response can occur under seismic loading as a result of nonstructural-structural reaction. These generally occur when the nonstructural component has some degree of rigidity and/or mass that causes an unexpected stiffening effect on portions of the structure.

Example: Nonbearing masonry walls, spandrels, shaft enclosures and stair framing, particularly when intermediate landings are tied to columns.

(2) The second action is the effect of the basic structure movement on the nonstructural components.

BUILDING DRIFT

The horizontal displacement of the basic structure can cause failure of the nonstructural components in flexible multi-story buildings. The drift design may be such that all floors do not drift at the same rate of time, thereby causing horizontal displacement between floors. Due to the action of the earthquake forces, movement can result in some floors of the building tending to move in one direction while the floors above or below are moving in the opposite direction. This differential movement between floors may or may not affect the performance of the exterior wall of a building.

Example:(1)

1. An exterior curtain wall that spans floor to floor in a simple span is seldom affected by cumulative action.

2. An exterior curtain wall that is anchored at each floor slab and is cantilevered both up and down can be severely affected and unless properly designed, the imposed racking of the elements can result in major failures of the wall system.

Simple shearing or racking action due to drift can be imposed on all floor to floor and some floor to ceiling components by differential lateral movement between floor systems. In some cases bending failures will occur because the movement is perpendicular to the component. Racking failures may occur when components are tightly fitted against columns due to the deflection action of the column.

(1) SEE FIGURE 1

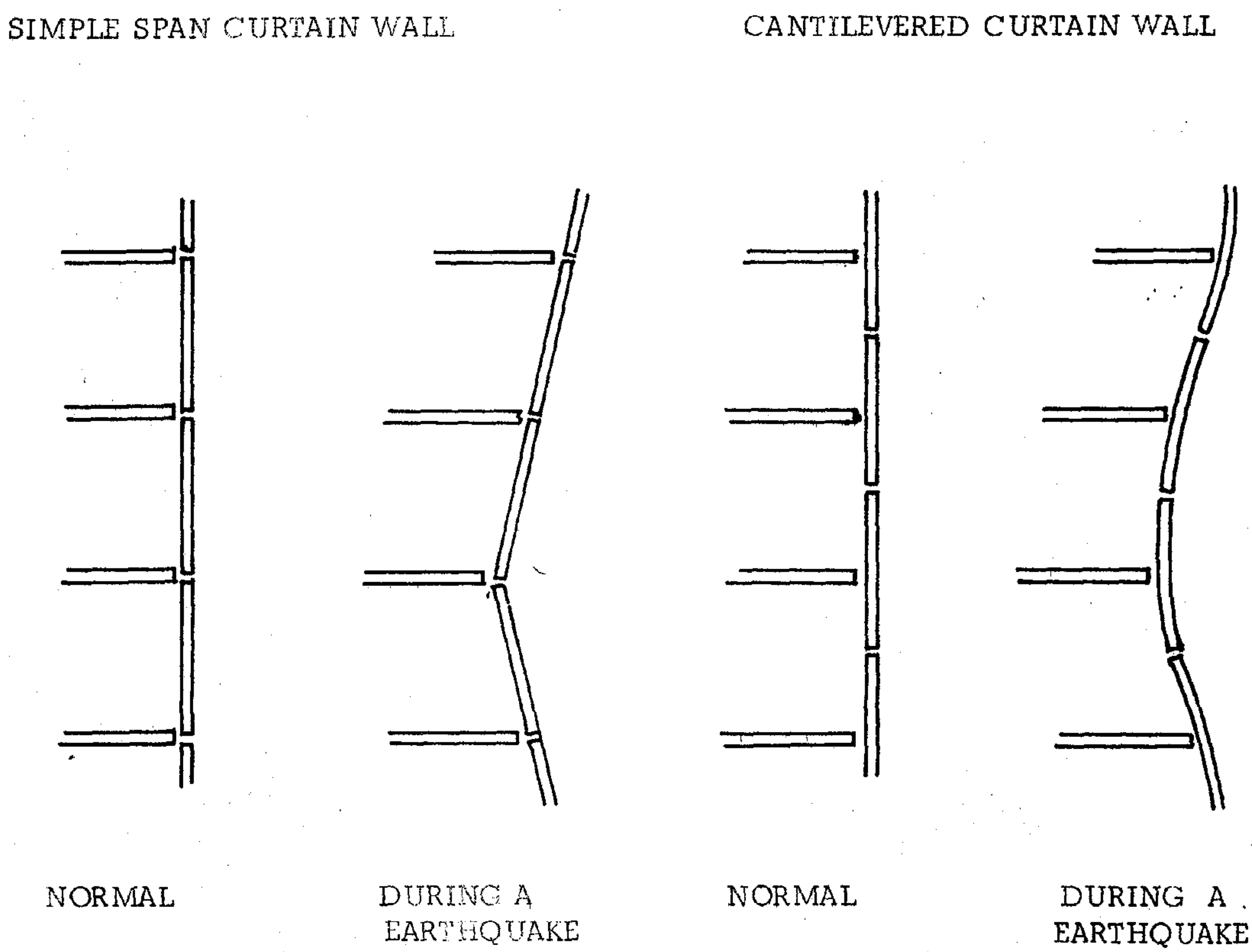

SIMPLE SPAN CURTAIN WALL
CANTILEVERED CURTAIN WALL
NORMAL
DURING A
EARTHQUAKE
NORMAL
DURING A
EARTHQUAKE

Figure 1

Example: Simple shearing or racking action due to drift can be imposed on floor to ceiling components by differential lateral movement.

Under severe seismic conditions foreshortening may occur, therefore causing a change in the floor to floor height thus crushing the nonstructural component.

BUILDING TORSION

This action, usually brought about by eccentric lateral resistance or mass of the basic structure causes the building to twist vertically. As previously explained torsion failure can result from the stiffness of a rigid or massive nonstructural component acting on another component. The basic effects of torsion on components are similar to drift.

UNRESTRAINED CANTILEVER MEMBERS

The unrestrained end condition of cantilever members can result in vertical displacement. Vertical displacement can be expected to be in opposite directions on adjacent floors. Since cantilever construction usually involves exterior walls these conditions can create hazard to life safety due to glass breakage and falling wall elements.

Example:[(2)] Cantilevers tend to exaggerate the joint rotation of the structural frame. Vertical displacement can be in opposite directions on adjacent floors.

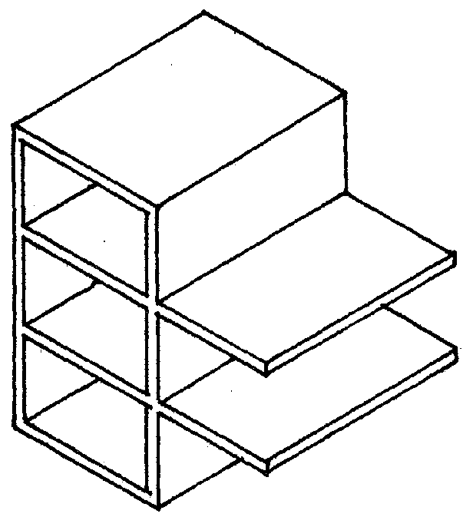
RESPONSE OF NONSTRUCTURAL SYSTEMS TO GROUND MOTION

Buildings and their nonstructural components should be able to undergo extended periods of ground shaking without failure. It is important that the designer understands that these forces and motions are transmitted to each component of the structure. Understanding the origins of the forces is vital in dealing with them in the design of nonstructural systems.

INTERRELATIONSHIP OF ARCHITECTURAL COMPONENTS

An interrelationship may exist between components and a failure of one component may cause a failure in another or ultimately the entire system.

(2) SEE FIGURE 2



Cantilevers tend to exaggerate the joint rotation of the structural frame.... vertical displacement can be in the opposite directions on adjacent floors.

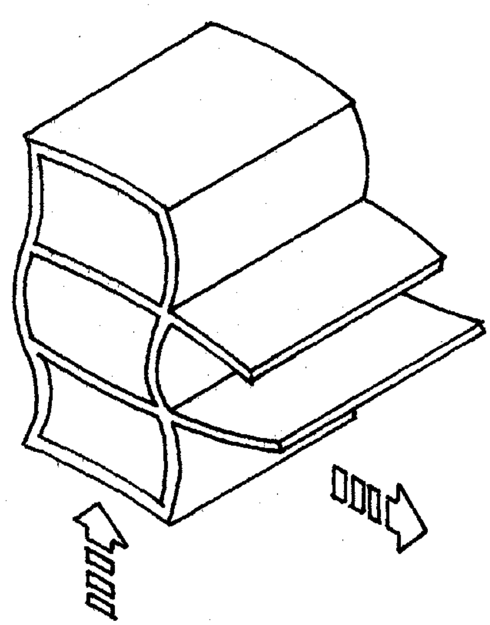


Figure 2

Example: A failure of masonry wall in a stair enclosure may cause the failure of the elevators, emergency power, as well as make the stair ineffective for egress.

The design of elements, systems or components that are in contact with or in close proximity to other systems must be given special attention to avoid damage or failure being induced when seismic motion occurs, i.e. if the ceiling supports the wall the intersection must be detailed to account for the effect of the movement of one in relation to the other.

DAMPING

The energy absorbing capabilities of nonstructural components are a function of the energy absorbing capabilities of the type of construction and materials used. Brittle materials will have little strength beyond their elastic limit while ductile materials can withstand many cycles of deformation into their inelastic range and will have considerable amount of energy absorption capacity. A combination of materials will sometimes produce nonstructural components that have excellent damping qualities.

ARCHITECTURAL SYSTEMS AND COMPONENTS

GENERAL

Let us review a previous statement about building code philosophy. The seismic resistance concept for a moderate earthquake should provide adequate protection that a building should continue to serve its function with the probability that light nonstructural damage will occur and no structural damage will occur. In a major earthquake, considerable amount of nonstructural damage will occur with some structural damage.

It is reasonable to assume that fire will accompany a moderate, and most certainly will occur after a major, earthquake. It is also reasonable to assume that fire fighting equipment or personnel will not be available to extinguish the fire or rescue the building occupants, therefore this present philosophy is suspect and certain standards for improving the performance of nonstructural systems and components and structure by the loss of fireproofing is required.

Let us look at the performance of some of the systems and their components.

EXITS - CORRIDORS

Unreinforced concrete masonry unit walls suffered extensive damage during recent earthquakes. One man was killed by falling masonry units at an exit stairways in the Alaska earthquake and there were numerous examples of exit stairs being littered by broken masonry units, thus making the exits ineffective as a means of egress. On the other hand, experience has shown gypsum board and lath and plaster partitions to perform favorably when secured to the floor, braced and partition loads properly anchored. Brittle finishes such as ceramic tile or masonry veneer can be expected to fail unless mechanical attachments are provided and racking eliminated. There were numerous instances of building exits being blocked by fallen lockers, furniture shelving and thin contents.

EXTERIOR WALL SYSTEMS

General

The performance of the exterior wall system is usually dependent on the horizontal displacement of the structure and the interrelation with other nonstructural elements. It is important that the building exterior wall system and the structural system be analyzed together.

Example:

1. If the structural frame is flexible, it will tend to transfer the load to the exterior wall.

2. If the exterior wall system is rigid it will resist lateral forces and will transfer its lateral load to the structure.

Let us look at some of the window wall components:

Precast Concrete Panels

Precast concrete panels can be designed to perform favorably, however heavy precast sections also add damage to the structure by shifting the center of gravity away from the center of rigidity of the building. This occurred at the J.C. Penney building in the Alaska earthquake. This was an example of a rigid facade attached to a flexible frame.

The 1976 UBC requires precast, nonbearing, nonshear wall panels to accommodate movement from the structure with the connections and panel joints to allow for three times the story drift. The connections are required to have sufficient ductility and rotation capacity to preclude fracture of the concrete or brittle failure in the welds. The precast concrete anchor is required to be hooked around the panel reinforcing steel or terminated in such a manner that it will transfer the forces to the panel. The connections are required to permit movement in the plan of the panel for story drift either by slotted or oversize holes or by providing other bending or ductile connections. This provision is clear in its intent and would have prevented many failures in previous earthquakes.

Curtain Walls-Windows

Curtain wall assemblies are ideal for light frame buildings where movement is anticipated. Where a high level of performance is desired tempered or laminated glass will minimize glass breakage. Gaskets or sealants that do not lose their resiliency with age or exposure are recommended. Allowances shall be made for proper clearance for glass movement in case of racking frames. The use of structural glazing gaskets is not recommended unless a rigid frame is provided. Ceilings and curtain pockets adjacent to window assemblies should be braced or proper clearance provided for building movement to avoid damage to the window unit.

Performance of curtain walls has been good. The Anchorage Westward Hotel, a fourteen story structure, had a minimum damange and there probably were good reasons for its performance. The curtain wall had joints at each floor and adequate clearance between the structure and members was provided which allowed the anchorage to flex and absorb energy as well as the design sufficient space for glass movement and the glazing seal was an ideal installation and the structure was relatively stiff.

Curtain walls are usually fabricated from aluminum, bronze or steel. The most common of these materials is aluminum because it can be extruded or formed with ease.

Annealed glass is commonly used, however, where glazing occurs in hazardous locations tempered or laminated safety glass is recommended. In addition to annealed glass there are other glass or glazing materials. The lack of sufficient clearance in the metal frame or frame to glass is the principal cause of curtain wall failure.

There are two common curtain wall systems:

The stick system consists of vertical support members and horizontal mullions. This type of curtain wall system is best suited for low rise buildings where there is a minimum amount of story drift or movement in the structural frame.

The unitized frame consists of individual frames which are independent of each other. This type of window is best suited for high rise buildings where story drift is expected.

Glass breakage levels are related to temper, fabrication, surface quality, support conditions and type of loading. Large lights usually break at somewhat lower stress levels than small lights. In small (or very thick) lights, deflections usually are small relative to the thickness. In large (or very thin) lights supported on all four sides, glass behaves like a membrane or diaphragm. Glass edges are seldom "fixed" or "damped", therefore glass is allowed to move within the frame. If sufficient space is allowed and the frame does not rack or glass loading does not increase due to falling objects or blast effect, good performance is expected. Heat strengthened glass is partially tempered making it approximately twice as strong and tempered glass is approximately three to five times as strong and its breaking pattern is granular, entirely into small pieces with no jagged edges. Where the designer desires to improve the performance of glass, he should consider using wire, tempered or safety glass.

Glass joint treatment is also a factor in overall performance of the curtain wall or window unit. If the edges are restrained, failure may occur. Sealants and gasket materials lose their resiliency with age and exposure, therefore the use of gaskets or sealants that will allow moverment are important.

Little earthquake knowledge is known about the use of glass in skylights and atriums, however one can assume that the earthquake experiences on curtain walls will be similar. Special attention should be given to the design of atriums where the glazed areas extend between two structures. Skylights should not be installed in exitways where there is a possibility of falling objects penetrating the skylight.

Masonry Walls

Masonry filler walls experience differential floor movement unless the structural frame is stiff or adequate clearances are provided between the structure for racking and drift. A wall fail example was the Elmendorf AFB Hospital masonry filler block walls with windows. The concrete blocks cracked, however the double glazed window units did not fail. A portion of that building consisted of two stories that was a relatively stiff frame and damage was minimal.

Veneers

Veneers include many nonstructural facings and are used as a wall surface, for ornamentation, protection or insulation. They are brick, stone, tile, metal or plastic.

Model building codes require that veneers be either adhered or anchored to structural or nonstructural systems.

Adhered veneer is limited to 36 inches (.9144 m) in the greatest dimension and 720 inches (18.288 m) in total area and a weight of no more than 15 pounds (6.80 kg). The adhesive must have a bond strength of 50 pounds per square inch (22.68 kg/6.45 cm).

Anchored veneers have no size limit, however the anchorage must support two times the weight of the stone.

Damage to veneers in earthquakes have been extensive. This is principally due to differential movement between the supporting element and the veneer. Quite often the joint between units is not large enough to allow for movement or the joint material bonds to veneer or flexible joint material is compressed beyond its working limit thus making a homogeneous unit. Sometimes the spot of plaster or cement will break loose from the structure and form a wedge between the veneer and backing and thus when movement occurs the wedge will move and finally break the anchor thus causing a chain reaction, breaking more anchors, then possible failure.

Experience indicates that it is better to have smaller wire anchors and many anchors rather than a few, mainly because the anchor wire metal fracture at tight bends. Veneers can also be anchored to rigid panels which in turn are anchored to the structure in such a manner that allowance can be made for movement. (3)

CEILING SYSTEMS

General

Suspended ceiling systems are damaged during earthquakes because they are usually free to swing on their suspension systems and batter against adjacent walls. They are also subject to pounding movement from light fixtures and mechanical equipment. Often ceiling systems carry partition loads. Systems of acoustic tile and board and plastic appear to sustain greater damage than rigid systems such as gypsum board and lath and plaster. Compression members and bracing will limit movement. (4)

Model building codes go into great detail, indicating how ceiling system should be installed. They prescribe hanger wire size and spacing in their standards, however there is ambiguity between the structural performance requirement of the code and the prescriptive requirement of the standard. The standard is also subject to interpretation for its requirements for uplift forces.

Acoustic Board and Tile Ceilings

Exposed tee bar suspended ceilings are easily damaged during an earthquake because the system may lack rigidity and supports to inhibit vertical movement.

Concealed splines suspended ceilings sustain less damage due to the ceiling tiles being tightly keyed together within metal splines.

(3) SEE FIGURE 3

(4) SEE FIGURE 4

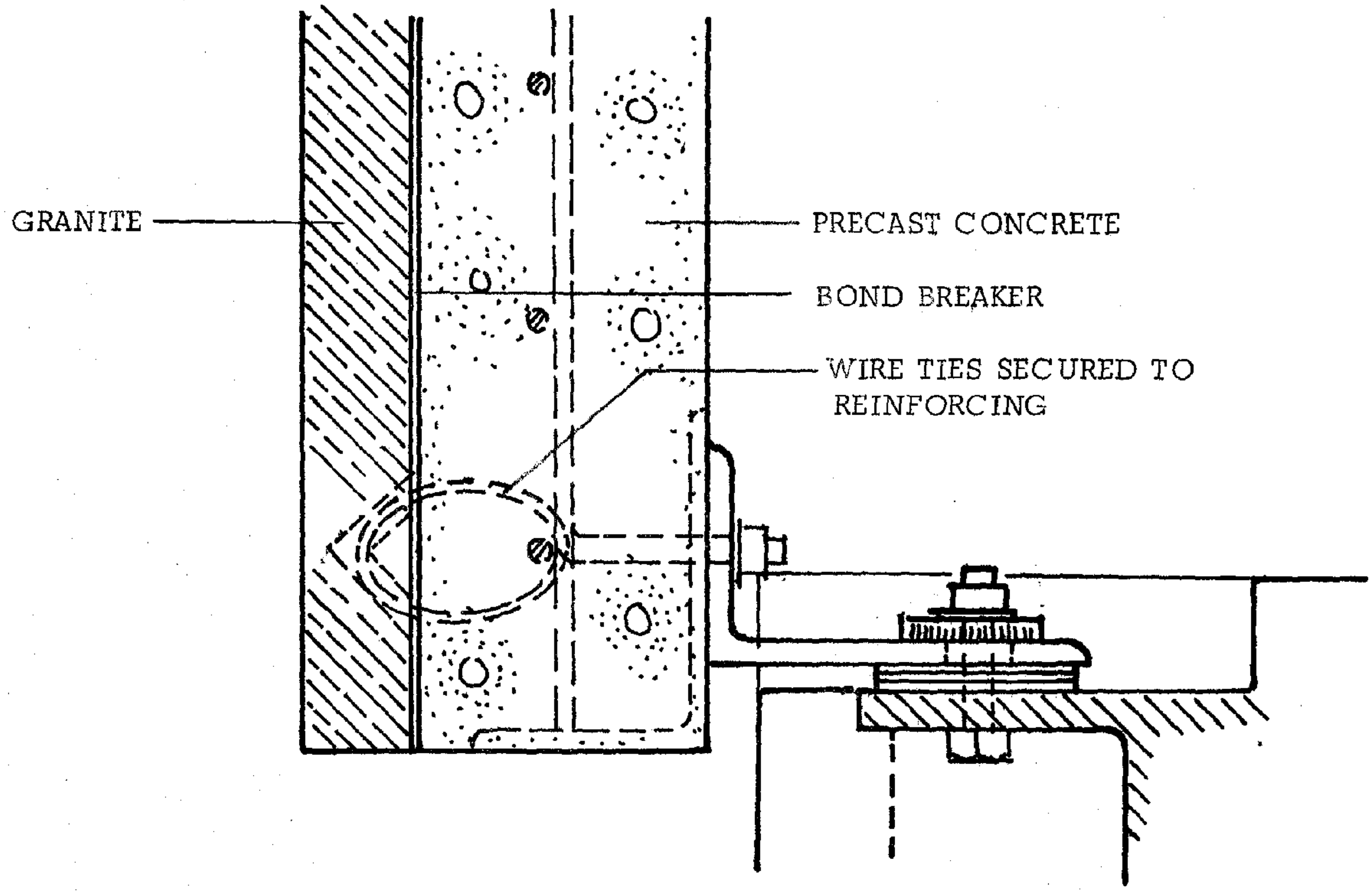
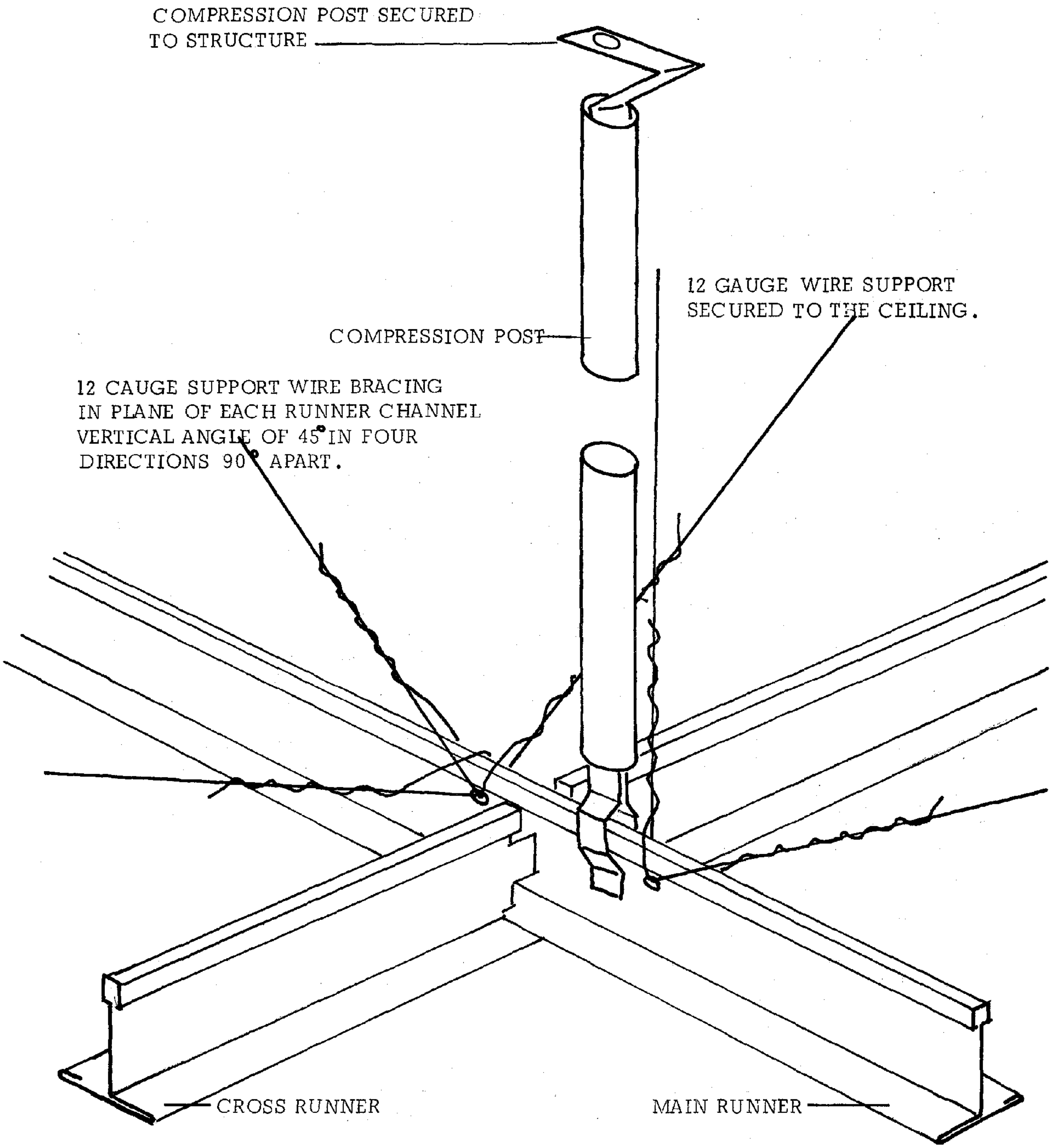

GRANITE
PRECAST CONCRETE
BOND BREAKER
WIRE TIES SECURED TO
REINFORCING

Figure 3



ACOUSTICAL CEILING COMPRESSION MEMBER

Figure 4

To avoid or limit damage, ceiling systems should be isolated from perimeter walls, braced to resist lateral and vertical movement. Braces should also be installed on adjacent ductwork and piping.

Gypsum Board - Lath and Plaster Ceilings

Gypsum board and lath and plaster ceilings are heavier and are more rigid than acoustic tile ceilings and usually do not sustain major damage except at exterior walls where they are subject to differential movement. To avoid or limit damage, ceiling systems should be isolated from the perimeter walls, braced to resist lateral and vertical movement. Braces should be installed on adjacent piping and ductwork to prevent pounding movement.

EQUIPMENT, ARTWORK, FURNITURE AND CONTAINERIZED ELEMENTS

Greater attention should be given to increasing the stability of free standing furniture, cabinets, shelving, lockers and artwork. These items should not be placed in areas where they could fall or block the means of egress or injure the occupant. Lockers and storage racks should be anchored at their base and braced if necessary. Consideration should be given to their contents.

During earthquakes loose objects are subject to acceleration and objects can cause damage to the occupant or other nonstructural elements. During previous quakes the records indicate that fire extinguishers become airborne missiles. In general, loose objects remain on shelves in low rigid buildings and are tossed about in tall flexible structures.

Heavy items such as stoves or other process equipment that burns fuel should be given careful attention to prevent fire or explosion.

Containerized equipment should be secured or designed with a low center of gravity with proper wheel design to prevent overturning. Computer floors should be adequately braced to prevent failure.

STORE FRONTS AND SIGNS

Earthquake experience indicates that it is difficult to predict the performance of large panels of glass. Indicated below are some of the principal causes of failure:

1. Interaction of the structure and nonstructural systems on the store fronts. Frequently portions of canopies, ceilings and walls will fall on and cause glass breakage.

2. Structural integrity of the store front system.

3. Glass and glazing failure. Glass itself is an unpredictable material. The edges may become damaged, glazing and gasket material may not allow the glass to move within the glazing stop, thus causing a failure.

4. Failure due to falling display material appears to be the greatest cause of store front failure.

Where increased protection performance is desired, it is recommended that store front areas be separated from building egress or the use of tempered glass, laminated safety glass or plastic be recommended.

It appears that signs do not offer a significant threat to life safety when they are secured to the building. Attachments into masonry and concrete should be avoided due to the possibility of failure of the anchorage. Signs should be designed to take earthquake structural movement in any direction.

STAIRS

Earthquake experience has shown that the performance of the stair system is related to the structural system. Stairwells are often placed within the building core among the rigid elements. Rigid stair systems usually fail in nonrigid structures or where shearing or racking in the floor system causes differential lateral movement between adjacent floors or lateral displacement. An example in the Alaska 1964 quake is found in the Hill building where the stairs in the lower stories are monolithic reinforced concrete and were damaged while the stairs in the upper stories are steel and were undamaged. The stairs in the Elmendorf AFB Hospital were reinforced concrete with a construction joint at the landing and were undamaged. Precast concrete stairs and metal stairs can be designed with connections that will allow for expected story drift without failure.

PARTITIONS

The performance of the partition system is related to the structure. Story drift can result in foreshortening of the relative floor to floor height and lateral movement may cause damage in the partition assembly if the partition components are tightly fitted against the structure. The designer should not expect earthquake imposed forces to run parallel to the partition assembly, the actual movement may produce the combined effect of shear, bending and crushing (if the wall is restrained). The performance of partition systems are sometimes affected by the interrelation of other nonstructural elements such as falling casework as well as the configuration of the partition itself. Partition systems fabricated from many components which are mechanically fastened and allowed to move usually perform better under earthquake movement than unreinforced monolithic materials such as clay tile and gypsum block.

Full height partitions are secured at the base and are either secured or braced to the structure or secured to a braced ceiling. Partial height partitions are either cantilevered off the floor or secured to the floor and placed in a manner that provides lateral stability to the wall. Movable partitions are secured similar to full and partial height partitions.

The performance of gypsum board and metal lath and plaster has been good during moderate earthquakes and can be improved by earthquake structural and nonstructural element analysis. Partition performance can be improved by providing joints that will allow for racking and deflection of the floor to floor system and the installation of control joints to limit cracking. (5,6)

The performance of wood, gypsum board and lath and plaster partitions has been good during moderate seismic movement and can be improved by a complete analysis of the structural and nonstructural building components. Other materials often used in wall systems are glass, plastics and wood and often other materials are veneered to partition systems increasing the load or possibility of failure.

DOORS AND FRAMES

The reasons for door and frame failures in earthquakes are obvious. The door assembly must function with normal frame to door clearances required for fire protection while the wall that it is attached to will be subject to racking and bending. Unfortunately, door systems are designed basically for fire protection and usually do not consider earthquake movement.

SEISMIC JOINTS

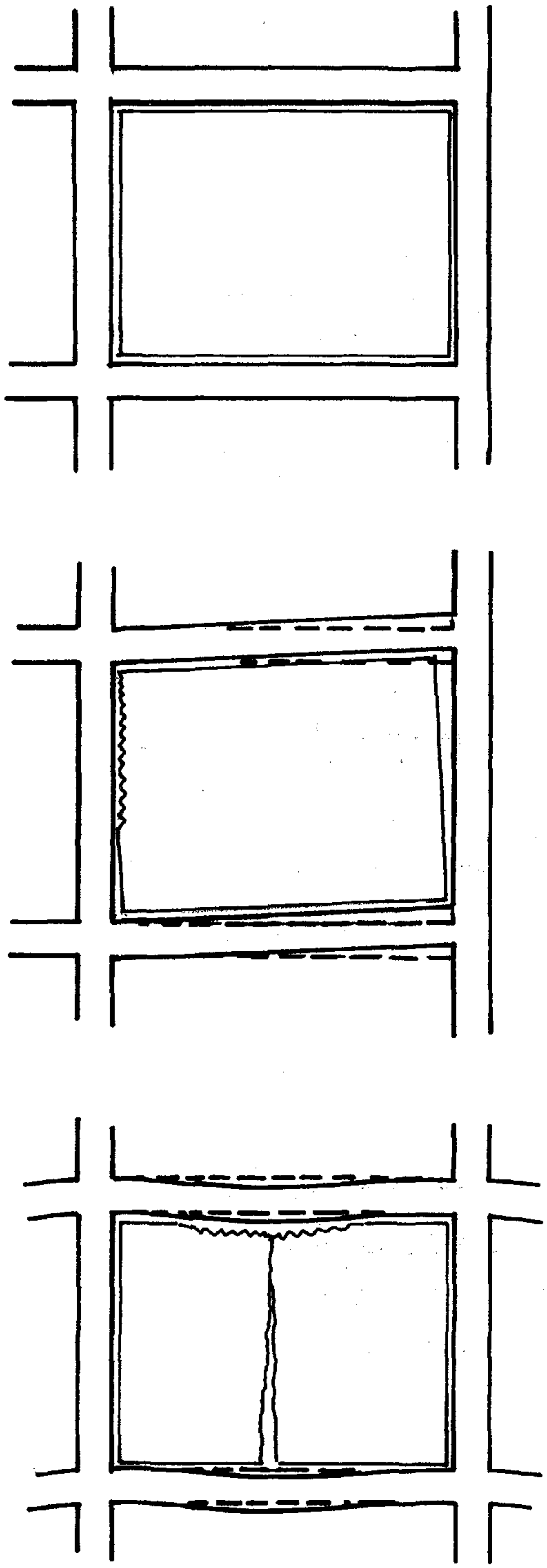
Seismic joints separate structural units of a building. They also occur in nonstructural walls and are subject to considerable amount of movement. Usually they are designed to provide for movement in a minor quake and to fail in a major quake. They are usually fabricated in such a manner that they will fail before causing failure of the adjacent wall or ceiling assembly. Seismic joints should be designed in such a manner that will not cause a failure in the wall or door system.

FIREPROOFING

Large destructive fires did not occur after the Alaska and San Fernando earthquakes, however minor fires occurred in areas where water service was not available. Fortunately, the fires did not occur in large metropolitan areas like the San Francisco 1906 quake or the Tokyo 1923 quake.

(5,6) SEE FIGURES 5 AND 6

PARTITION CRACKING

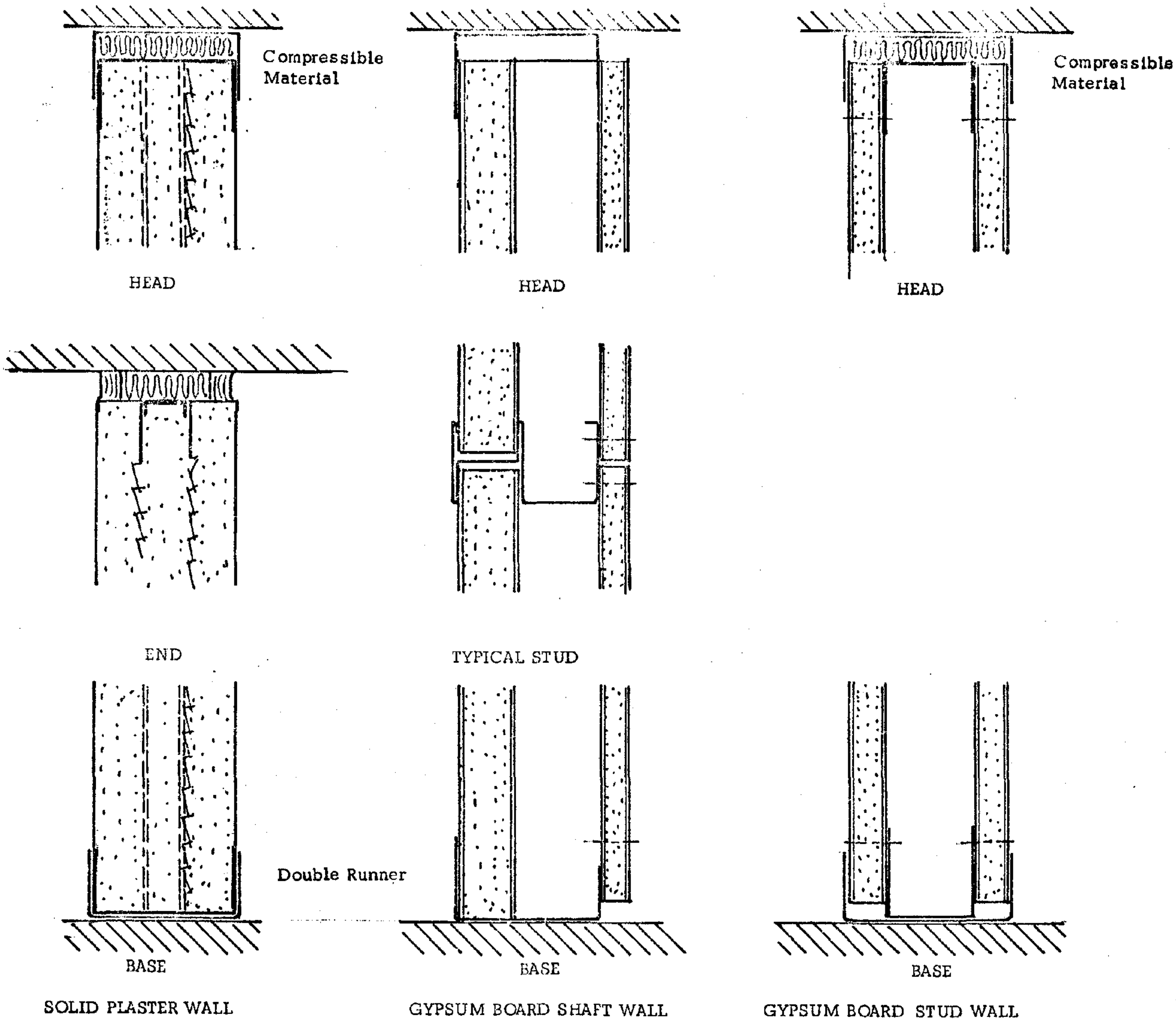


NORMAL

CRACKING DUE TO STRUCTURAL RACKING

CRACKING DUE TO DEFLECTION

Figure 5



PERIMETER RELIEF TO NON BEARING PARTITIONS

Figure 6

There is reason to believe that fires will occur and water for fire fighting personnel will not be available. Therefore structural fire protection integrity of the steel frame is important in view of the building content combustible loading. It is assumed that 75 percent of the fireproofing should remain in place (percentage not based on area but protection - 4 hours would become 3 hours).

CANOPY AND ROOF SYSTEMS

Canopies when properly anchored to the structure and designed to withstand seismic loads in any direction will perform satisfactorily. However, canopies may be susceptible to damage due to the fact that water and corrosion may weaken their structure.

As a general rule, nonstructural roof coverings have performed as well as their structural backing. Heavy roofing units such as clay tile and cement tile should be avoided unless methods are developed to contain the broken tiles as well as provide metal attachment that will not be subject to failure due to moisture and corrosion.

Roof screens and their attachments should be properly designed so that they will not fall over or through the roof structure.

MASONRY WALLS

We had previously discussed the performance of exterior walls and exterior masonry. The interior masonry wall failures in earthquakes have been numerous, however the performance of the interior wall can be improved by isolating the wall from the structure on the sides and top and providing structural support to the masonry wall. A noncombustible fire rated material can be placed within the void, thus providing a rated wall if necessary.

IMPORTANCE OF CONNECTIONS AND FASTENINGS

GENERAL

At the present time, the design of many of the construction details and connections are based on local custom and practice and do not consider seismic loading.

Architects are urged to give full consideration to the design of connections and to see that the design intent is followed in shop fabrication and field supervision. Often the design intent is overlooked on shop drawings and failures occur.

The weakest link in architectural nonstructural component design is the connections. A careful review of failures reveals this to be a fact. Stress seems to be the primary factor. Stresses tend to concentrate or change direction and often exceed the limits of design.

Some of the causes of stress failure are indicated below: (7)

INADEQUATE TOLERANCES

Inadequate tolerances for seismic movement will often transmit loads to adjacent parts. This tolerance is often confused with construction tolerances. Tolerances should be in addition to construction and manufacturing tolerances.

INADEQUATE BEARING ON FASTENINGS

This is most evident in screw thread fastenings where the thread reduces the cross section area of the fastening. Excessive bearing pressure may cause screws to "pull-out" such as screws pulling out the aluminum screw slots.

IMPROPER DETAILING

The adjustable anchor such as the double angles clip is used often on curtain wall work. Frequently, the lack of bearing may cause improper distribution of the loads.

IMPROPER WELDING

Welds should be considered as a brittle connection. Welds build up local internal stresses, particularly at end joints. These residual stresses can increase the chance of failure when the connection is stressed due to movement or seismic action.

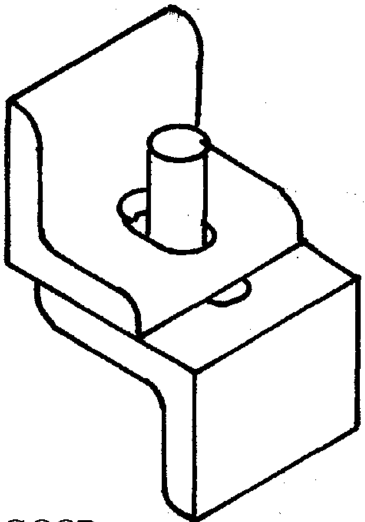
Light guage welding oftens results in burn thru welds especially when welding a light gauge metal to heavier structural shape. Tack welds are not considered as a structural weld due to their noneffectiveness. Welding light guage galvanized metal may be suspect due to gas pockets which will reduce the strength of the weld.

EARTHQUAKE DAMAGE MITIGATION

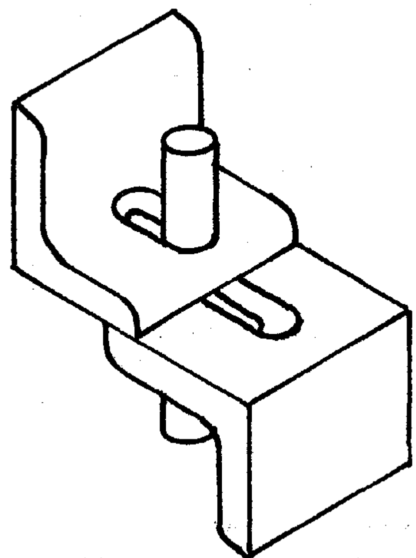
The total cost of possible damage of nonstructural components in an earthquake of moderate or major intensity cannot be measured in dollars and cents alone. Damage may include loss of life, injury, property damage, as well as social and economic losses.

Virtually every nonstructural system is subject to damage and it appears we do not have sufficient knowledge of earthquakes or how to prevent damage to nonstructural systems and their components. The architect, engineer and client must make the decision as to what system should continue to function or to what limit damage must be tolerated.

(7) SEE FIGURE 7

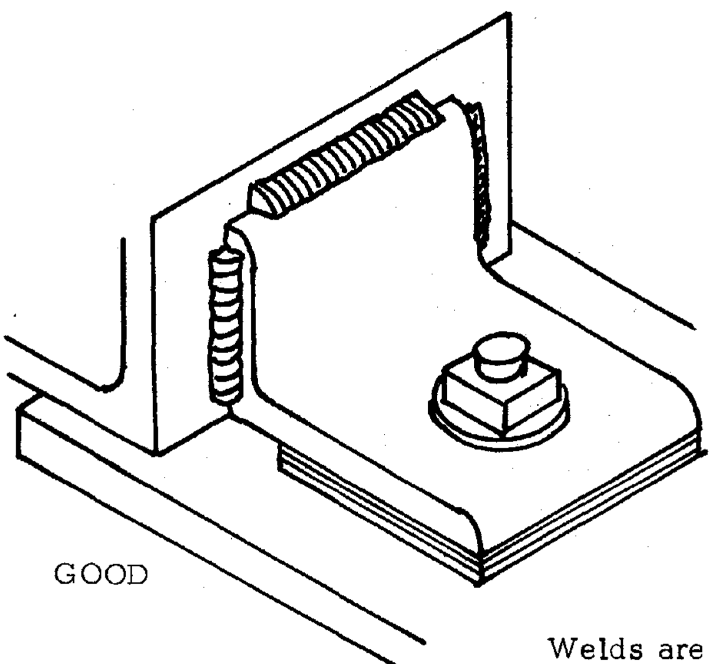


GOOD

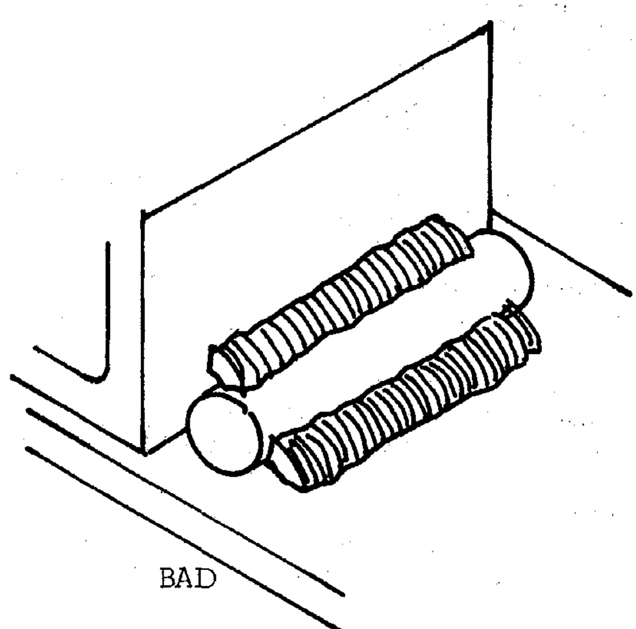


BAD

Often a connection is designed with structural consideration in its normal position and not in the actual location and is subject to greater design stresses.



GOOD



BAD

Welds are often detailed in working shear.

Figure 7

Indicated below are examples of costs to improve the performance of nonstructural components.

1. Acoustic tile & board ceilings: Hold down clips, diagonal wire bracing and compression members. 15 cents per square foot.

2. Concrete block: Provide angles at top and ends. $8.00 per lineal foot.

3. Gypsum plaster relief angle top and bottom. 70 cents per lineal foot.

4. Gypsum board relief angle at top. 50 cents per lineal foot or 5 cents a lineal foot for increasing the size of the runner channel to a 3 inch (7.6 cm).

On the other hand, the cost of improving the performance of a curtain wall or precast panel anchor could be minimal, just common sense. We assume that increasing the earthquake performance will cost something. How much are we willing to pay? What are the risks?

SEISMIC PLANNING FOR ARCHITECTURAL SYSTEMS AND COMPONENTS

For proper seismic planning it is essential that the architect utilize a "team" approach for all aspects of design consisting of the architect, structural engineer, foundation engineer, mechanical, and other professional constultants. The client should be aware of the cost/benefit and risk analysis.

There has been a growing change from the original building code philosophy which was basically oriented toward the structure rather than to life safety of the occupant. Since the mid 1960's there has been a growing concern that certain types of building occupancies should remain in place and function after a major earthquake.

The 1976 UBC adopted provisions establishing "Values for Importance Factor" which requires that hospitals and other medical facilities having surgery or emergency treatment areas, fire and police stations and municipal government disaster and operational stations and communication centers be designed and detailed to remain operational after a major earthquake. In addition, the building code established additional requirements for story drift.

NONSTRUCTURAL PLANNING

The Applied Technology Council (ATC) is in the final review process of preparing a document known as "ATC-3-05 Recommended Comprehensive Seismic Design Provisions For Buildings". The basic object of this document is to present the current state-of-knowledge in the fields of engineering, seismology and engineering practice. The primary concern of this document is that neither the structural framework of the building nor its component members would fail in a severe earthquake, and that certain critical facilities, particularly those essential in case of emergency would remain operational.

The document assigned seismic hazard exposure classifications for all buildings based on relative hazard to the public based on use of the building. Group I usage represented the highest level.

Group I buildings consisted of buildings housing facilities which are necessary to post disaster recovery and require continuous operation during and after an earthquake. Buildings which were adjacent to Group I buildings which would fail and create a hazard would be assigned the same classification.

Group II buildings include buildings housing a high density of occupancy or which restrict the movement of the occupants.

Group III buildings housing all other uses.

When a building contains more than one occupancy group the document recommends using the group of the higher occupancy when the use exceeds 15 percent of the total floor area.

Listed below are representative occupancy types for the three groups.

Group I	Group II	Group III
Fire Facilities	Public Assembly more than 100	Aircraft Hangers
Police Facilities	Open Air Assembly more than 2000	Repair Garages
Hospitals and Emergency Operating facilities	Day Care Centers	Service Stations
Power Plants	Schools	Dwellings
	Colleges	Townhouses
	Retail Stores more than 5000 SF	Retail Stores
	Shopping Centers more than 20,000 SF	Public Assembly less than 100
	Office Buildings	
	Hotels	
	Detention Facilities	
	Hospital other than Group I	
	Factories	
	Hazardous Occupancies	

The document recognizes the following:

1. Failure in an adjacent structure may cause the means of egress to be blocked therefore proper planning is necessary.

2. Certain nonstructural systems should perform better than others and the performances should be related to the occupancy group.

3. There is an interrelation with other non-structural elements that should be considered in the building design performance.

4. Connections of components on the nonstructural systems are probably the most important factor in the performance of the systems.

This document establishes minimum lateral performance requirements for nonstructural systems including components and their connections with performance criteria and seismic coefficients for the various systems based on seismic exposure groups.

The performance criteria and seismic coefficients are determined by broad assumptions based on the current knowledge of damage caused by earthquakes and judgement of the committee writing the document. In addition, the document requires detailing of connections and special inspection to determine compliance.

CONCLUSION

The architectural concept has a direct bearing on the seismic resistance of a building and the mitigation of hazards resulting from an earthquake. The architect must consider all elements of the design including the architectural systems and their components into his design in a logical form rather than a series of unconnected parts.

If an architectural system or component fails the mode of failure is probably related to:

1. Faulty design of the element.
2. Interrelation with another element that failed.
3. Interaction with the structural system.
4. Deficiencies in the type of mounting.
5. Inadequacies of its connection.

The design of nonstructural systems and components must be based on experience and theoretical knowledge of structure and nonstructural systems and earthquakes, as well as the building codes. Testing for nonstructural systems and components under seismic conditions are currently needed and this information made available to the designer, manufacturer and installer. Thorough and competent inspection by knowledgeable personnel is necessary to insure that the intent of the designer is executed.

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SEISMIC DESIGN : BUILDING NONSTRUCTURAL SYSTEMS

K. L. Merz

CONTENTS

INTRODUCTION

The nonstructural components of a building include facades, curtain walls, ceilings, partitions, elevators, lights, electrical power systems, fire protection systems, telephone and communication systems, storage racks, and even large pieces of owner-supplied furniture or portable equipment. In the past, the usual structural design procedure has been based on the philosophy that to design a building to avoid all damage during a major earthquake is not economically justifiable; the structural system of the building is intended to be deformed by strong ground motion, and damage to some of the nonstructural elements is expected. However, recent major earthquakes (Alaska 1964, San Fernando 1971, Managua 1972, and Guatemala 1976) have caused considerable damage to the nonstructural elements and electrical/mechanical equipment of buildings sustaining only moderate structural damage. The investigation (1-7) of the damage caused by these earthquakes has indicated the need for architects and designers of nonstructural building systems to acquire background and additional skills in the analysis and design (8) of these systems for the building dynamic environment caused by the structural response to earthquake ground motion. An even greater emphasis is provided by the fact that approximately 70 percent of the construction cost of a building is for equipment and nonstructural elements. An increasing concern over the life-safety aspects of building design is also apparent. Thus, not only must the substantial monetary investment in nonstructural elements and equipment be protected, but also the systems concerned with insuring life-safety must be made seismic resistant. We must modify our design philosophy that a building is safe if it survives an earthquake without damage to the structural system. The structural frame may absorb the earthquake forces without significant damage, but the movement of the building induces significant secondary damage to nonstructural elements. A building is not safe if, during an earthquake, light fixtures and ceilings fall, elevators do not operate, emergency generators do not come on, loose objects block exits, and broken glass falls into the street. A building is not properly designed if an owner sustains huge losses due to nonstructural damage.

By definition, the nonstructural components of a building are those elements and materials that are not part of the structural system. The structural system, or building frame, is designed to withstand the live and dead loads of the building, in addition to wind and earthquake forces, without the assistance of the nonstructural components. However, the participation of nonengineered filler walls and other nonstructural elements in the total structural response has been noted in post-earthquake building damage analyses and is an increasing concern of structural engineers. The distribution of nonstructural walls can force a torsional response in symmetric buildings, alter the system frequency response and damping characteristics, and create loading conditions on structural elements for which they were not designed. Comparisons of nonstructural damage noted in recent post-earthquake damage studies (3,7) between reinforced concrete ductile frame and shear wall building construction have been striking. The control of inter-story drift in the design of ductile frame structures is a critical problem, both from a structural standpoint and from an architectural detailing standpoint.

Attention was first focused upon the subject of nonstructural damage during the extensive investigation and categorization of damage due to the Great Alaska Earthquake of 1964 (1). The investigation (2) of the damage caused by the 1971 San Fernando Earthquake has again indicated the consequences of ignoring the seismic design of nonstructural systems. Additional documentation of nonstructural damage to buildings can be obtained from several sources (3-7). Review of this damage documentation provides an excellent overview of the problem and provides a good experience base for making design decisions on the proper detailing of nonstructural systems. It should be noted that the most predominant source of damage to equipment is the lack of attention to anchorage points or restraints. The lessons learned by detailed studies of damage sustained by earthquake-tested buildings must be carefully reviewed by both architects and engineers. One lesson from past earthquakes is clear: the amount of damage sustained by nonstructural building components could have been greatly reduced by relatively inexpensive corrective measures.

BUILDING DESIGN CONSIDERATIONS

The development of plans and specifications for a modern building is a team effort. An architect acts as a coordinator and general manager of the project as it moves from concept to design and into the field and is finally erected. The primary outside consultants on the design team are the structural, mechanical, and electrical engineers. An additional outside consultant is usually retained to design the elevators. The structural engineer and the architect require the services of foundation and soils engineers, and continual liaison with material manufacturers and governmental agencies by all team members is necessary in the development of the design. This outside group of consultants often controls the design of 75% of the total construction cost of a building.

The first concept of the size and shape of a building are developed by the architect from his knowledge of the client's needs. In most instances, the fundamental decisions are rendered before the structural engineer is called to develop a structural frame to meet an architectural design and before mechanical and electrical engineers are called in to design their systems. Thus, the architect has the initial responsibility of advising the client of the necessity for considering the seismic design of nonstructural components within the proposed building. As the leader of the design team, the architect controls the level of consideration given to the seismic design of nonstructural components of buildings. Much of this consideration must be done in the schematic design phase so that the costs for such considerations are included in the initial cost estimates.

Adherence to building code requirements concerning nonstructural seismic design will not in itself ensure that its provisions will be properly applied by the design team or installed by the contractors. Most of the problem stems from the traditional divisions of responsibilities between design professionals, and a construction industry that does not require careful detailing of nonstructural elements. It is during the preparation of the working drawings and specifications that the final decisions are made regarding the detailing -- or lack of detailing -- of the nonstructural components for seismic resistance. Often the mechanical and electrical drawings are schematic only, with the design and installation requirements contained within the written specifications. Because the documents are prepared for competitive bidding, alternative equipment and materials must be accepted if they are equal in quality and performance to those specified. Shop drawings prepared by the successful contractors or materials manufacturers must be submitted to the design team for approval before installation. These shop drawings contain the actual installation details and become the final guide to the execution of the design. This shift from the plans prepared by the design team to the shop drawings and then to the work of the installer at the building requires careful supervision if the intent of the design is to be executed properly. Many of the installation details of nonstructural elements are deliberately omitted from drawings because of long-standing trade practices that have left many of these decisions to product manufacturers and installers. To overcome these problems, all members of the design team must see that all nonstructural elements are detailed or carefully described in the specifications. The architect must lead the design team to defend these details from contractor proposed alternates that do not meet the design intent and insure that they are properly executed in the field.

CURRENT SEISMIC CODE PROVISIONS

Most building owners, and unfortunately their architects and engineers, consider building code minimum requirements as adequate protection against earthquake damage, and they will not increase their capital costs to improve occupant safety or reduce future repair costs. This firm belief in the infalibility of building codes is usually badly shaken after each earthquake. But memories are short and the magnitude of repair costs and other post-earthquake difficulties with buildings are not made public, so owners usually resist added costs for earthquake resistive features that are not spelled out in a code. Thus, recent legislative efforts have been concerned with upgrading codes, especially for "critical" facilities.

After the 1971 San Fernando earthquake, in which several modern hospital buildings and equipment were seriously damaged, the California Legislature enacted The Hospital Seismic Safety Act of 1972. The implementing regulations (9) which have been adopted are the first government code to link geology, seismology, structural engineering, and nonstructural building design. The regulations, which are the most complete concerning nonstructural building components to date, require that nonstructural components and equipment resist the application of an equivalent lateral static force which can be equal to the equipment weight (i.e., 1.0 G acceleration). The dynamic design of equipment is allowed as a "footnote" type option. The nonstructural requirements of Title 17 are summarized in Appendix Table 1. Considerable experience has been gained in the administration of the regulations in current California hospital construction. A comprehensive document (10) is under preparation which will give design guidelines for acceptable nonstructural detailing practice consistent with the intent of the regulations. The concern over hospital earthquake resistance is not limited to California. The military services and the Veterans Administration have standard requirements (11, 12) for the seismic design of hospital facilities, including nonstructural elements.

Recent changes to the Uniform Building Code (13) have also upgraded the lateral force coefficients for nonstructural components. These new UBC requirements are summarized in Appendix Table 2. The design guidelines utilized for GSA buildings (32) should be noted. The current efforts of the Applied Technology Council (ATC-3 Project) to review the state-of-the-art in earthquake engineering and develop comprehensive seismic design recommendations (14), including nonstructrual components, should also be noted.

It should be observed that there is a considerable gap between the equipment qualification procedures used in normal commercial building design, including hospitals, and those utilized in critical military and utility facilities (15). Building equipment design requirements are based upon application of an equivalent static force to insure proper anchorage and enclosure or support strength. The problem of functional performance is not addressed. Equipment items deemed critical, such as life safety system components (fire pumps, smoke ventilation, elevators, etc.) are simply designed for higher levels of equivalent static force in an attempt to obtain performance. This philosophy is valid for non-critical equipment, given the damage patterns noted during past earthquakes, which indicates that a great majority of damage can be prevented simply by expedient restraint of building service system equipment. But critical equipment such as emergency power systems, whose function is mandatory, cannot be qualified by application of anchorage requirements. Some code work (NFPA,ASME) in this area is currently under development.

BUILDING DYNAMIC ENVIRONMENT

Usually, the structural engineer is the only member of the design team to analyze the effect of dynamic building forces induced by earthquakes. All members of the design team, however, must inform themselves of the nature of earthquake-induced forces in buildings and of the manner in which the stress paths occur between the structural and nonstructural elements of a building. The net resistance of the nonstructural elements with floor-to-floor connections contributes to the overall stiffness of the structural system, thus influencing the dynamic response of the building. The resulting damage to nonstructural components shows a lack of knowledge among nonstructural designers of building response characteristics due to an earthquake. Since the majority of building service equipment is located both on the ground floor and roof, the nonstructural designer must understand the characteristics and response effects of both ground motion and floor motion.

BUILDING AMPLIFICATION OF GROUND MOTION

Since 1965, the City of Los Angeles has required placement of three strong motion accelergraphs in all new structures greater than six stories in height. Subsequently, adjacent municipalities have adopted similar requirements. These instruments are placed in the basement (base level), mid-portion (intermediate level) and near the top (upper level) of buildings as shown in Figure 1. The 1971 San Fernando earthquake may be viewed as a full-scale experimental test of a wide variety of building types to strong ground motion. Forty-nine buildings, ranging in height from 7 stories to 43 stories, recorded motion in three component directions at the base level and at least one higher level. These buildings were located at distances from the epicenter ranging from 20 km to 83 km and were exposed to peak horizontal base (ground) accelerations ranging from 0.030 G to 0.255 G and peak vertical base accelerations ranging from 0.010 G to 0.171 G (1G=980.6 cm/sec/sec). The resulting peak horizontal upper level floor accelerations ranged from .08G to .50G while peak vertical upper level floor accelerations ranged from .04G to .36G. The uniformly processed, digitized, corrected, and analyzed data set for these recorded accelerograms has been published (18 - 20).

A structural system acts as a mechanical narrow-band filter for earthquake ground motion, amplifying and filtering at approximately the modal frequencies of the building. The resulting floor motion becomes the input base motion for anchored (and unanchored) equipment. The severity of floor motion is usually measured by the peak floor acceleration which is physically understood as a measure of the maximum inertial force that must be resisted by a rigid, anchored object. Recent studies (16, 17) have characterized the amplification of building motion by the ratio of peak output (floor) acceleration to peak input (base) acceleration. This comparison yielded average values for a large sample of building types, heights, and construction of recent design. The understanding of the response behavior of a building subjected to ground motion is complicated by the effects of three dimensional motion, coupled torsional-lateral response, and nonlinear behavior. A great many parameters influence the response of a particular structure including the frequency content of the ground motion at the building site, soil-structure interaction, discontinuities in structural framing, the detailing of the structural connections, and even the stiffness of the nonstructural components. In addition, the recorded motion represents the response of a singular point within the structure, thus a wide range of values should be expected when using the extreme or maximum peak values as a measure of response severity.

An example of a recorded reinforced concrete frame building response is shown in Figure 2 for a duration of 35 seconds. The nonlinear filtering behavior of the building is easily noted by the comparison of the base level accelerograph record with the upper level. The frequency of response during the first 10.7 sec. has considerable higher frequency content than the latter 24.3 sec. of record. A more detailed evaluation of the recorded floor motion reveals that the average period of

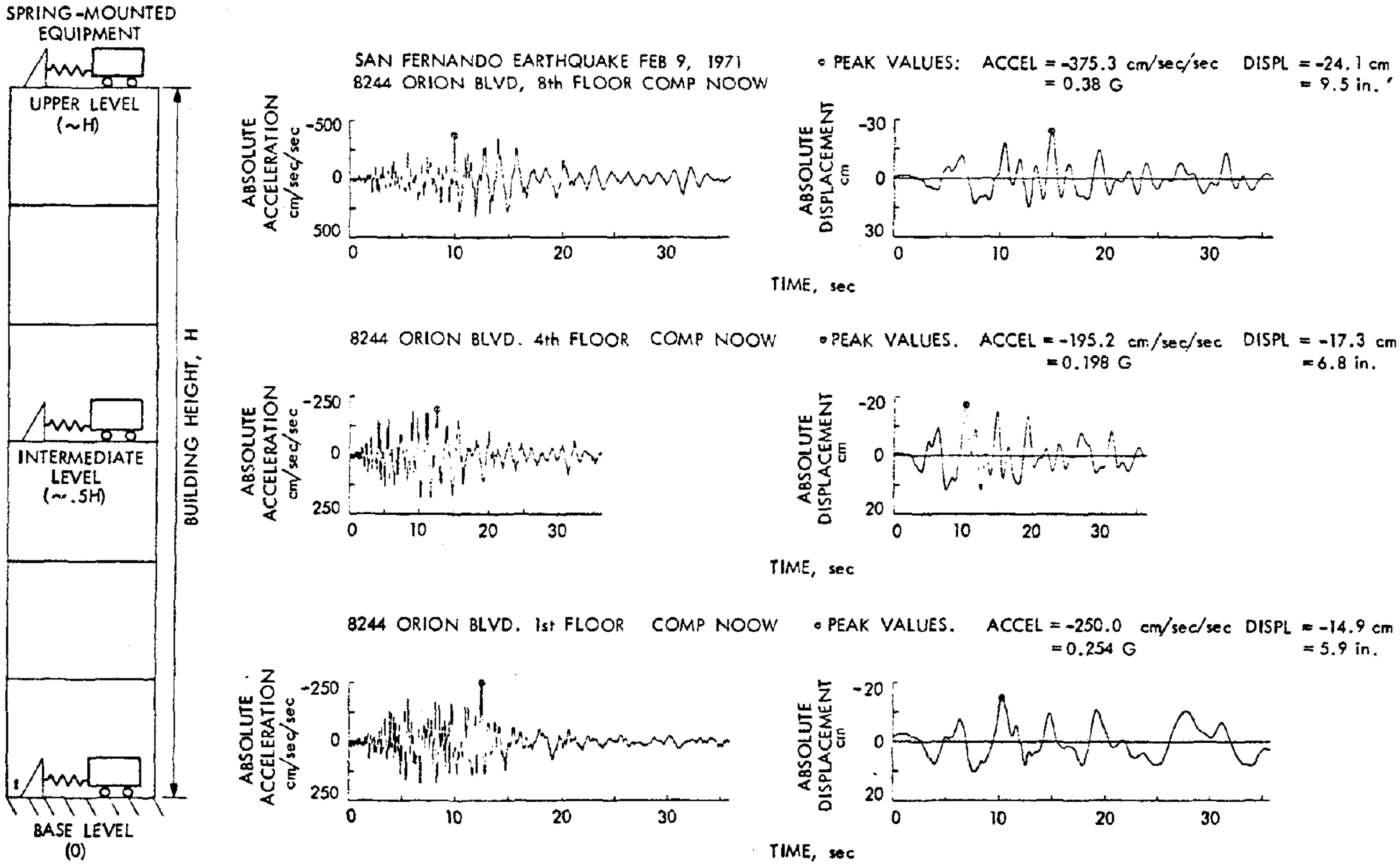

FIGURE 1. EXAMPLE OF RECORDED BUILDING RESPONSE, 1971 SAN FERNANDO EARTHQUAKE.

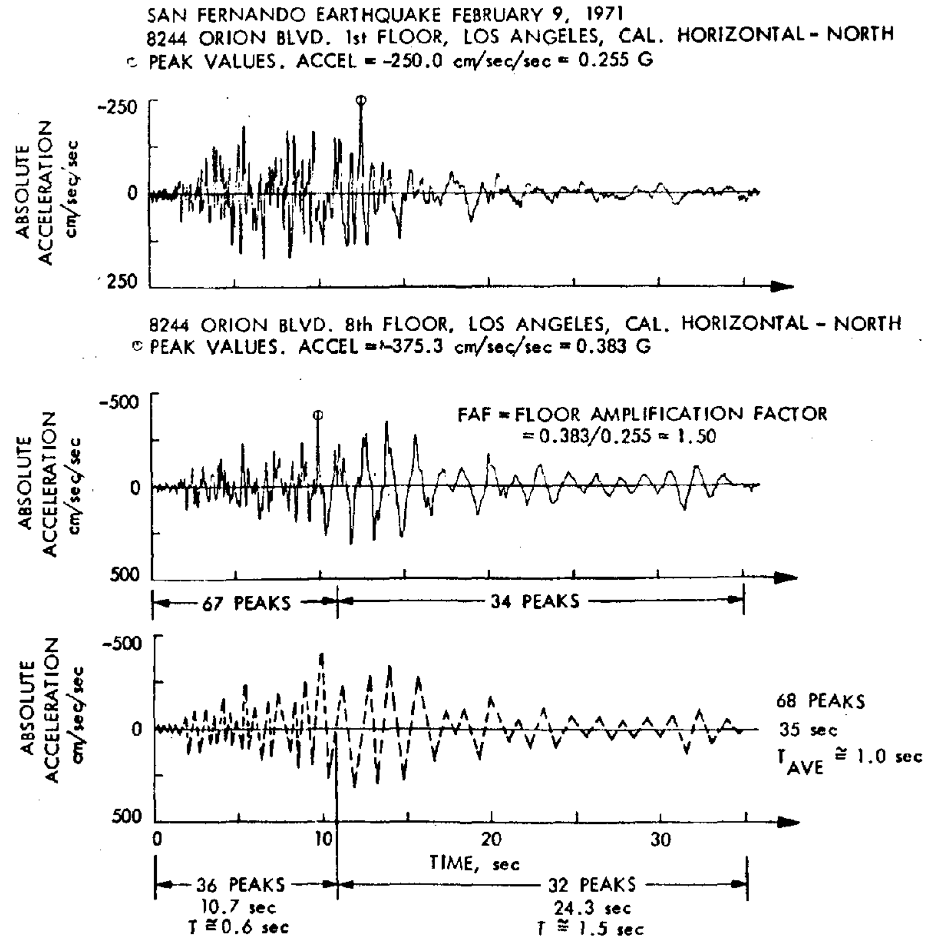

FIGURE 2. EVALUATION OF RECORDED BUILDING MOTION.

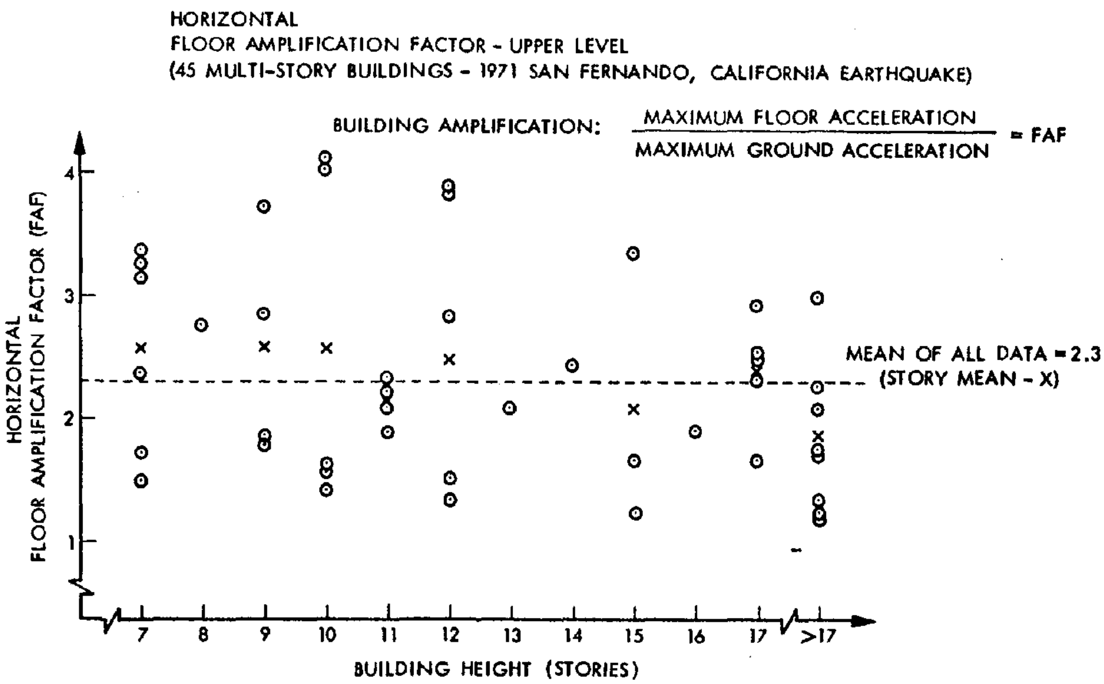

FIGURE 3. HORIZONTAL UPPER LEVEL BUILDING AMPLIFICATION.

response during the first portion of the record is approximately 0.6 sec. and then lengthens to 1.5 sec. for the remainder of the record. This particular building was the subject of a detailed post-earthquake study (22,23) which noted that the interior partitions and exterior cement plaster walls reduced the design response period by 30% and accounted for approximately 60% of the initial lateral force resistance of the structure prior to cracking.

The horizontal amplification characteristics (16) of the buildings during the 1971 San Fernando earthquake are given in Figure 3 which compares the computed FAF (Floor Amplification Factor) over the range of story heights reported (21) for the 49 buildings. As can be noted from Figure 3, the amplification behavior of the buildings is relatively independent of story height with an average horizontal FAF value of 2.3. In Figure 4, the largest horizontal FAF is compared to the largest peak ground acceleration, disregarding component direction. This comparison indicates a trend of decreasing building amplification with increasing peak ground acceleration. Assuming that peak recorded base acceleration is a measure of the overall strength or intensity of ground motion, we observe that the amplification decline may be attributed to the energy dissipation caused by accumulated structural damage. However, any use of the data to indicate a definite trend should be viewed with caution due to the few data points greater than 0.20G horizontal and 0.10G vertical. Figure 5 indicates the distribution of horizontal amplification over building height.

Vertical amplification of ground motion is another important consideration for nonstructural components and equipment. Figures 6 and 7 present the vertical amplification characteristics of the group of buildings with recorded motion. Again, the amplification behavior of the buildings is relatively independent of story height with an average vertical FAF value of 2.6. Both horizontal and vertical components have the same average amplification, FAF = 1.8, for the intermediate levels.

SPRING MOUNTED EQUIPMENT RESPONSE

Given that an equipment item is properly anchored (i.e., not susceptible to overturning or sliding), the equipment will respond to the floor motion as an independent structural or mechanical system. Rigid equipment, such as motors, pumps, etc., which are directly mounted to the floor will not experience significant additional amplification. However, building service equipment is often placed on spring mounts, or vibration isolators, to reduce the transmission of equipment vibration to the structure (and tenants). The failure of vibration mounts and the resulting overstress of connecting pipe and conduit is a frequent observation during post-earthquake damage surveys. The specification of spring mounts with 1.0 in. (2.54 cm) static deflection and equal vertical and lateral stiffness is a common practice for building service equipment (resulting in equal vertical and horizontal natural frequencies of 3.1 cps (Hz). The analysis (20) of the recorded building motions provides the data necessary for the determination of the response of spring mounted equipment. Using the ratio of peak equip-

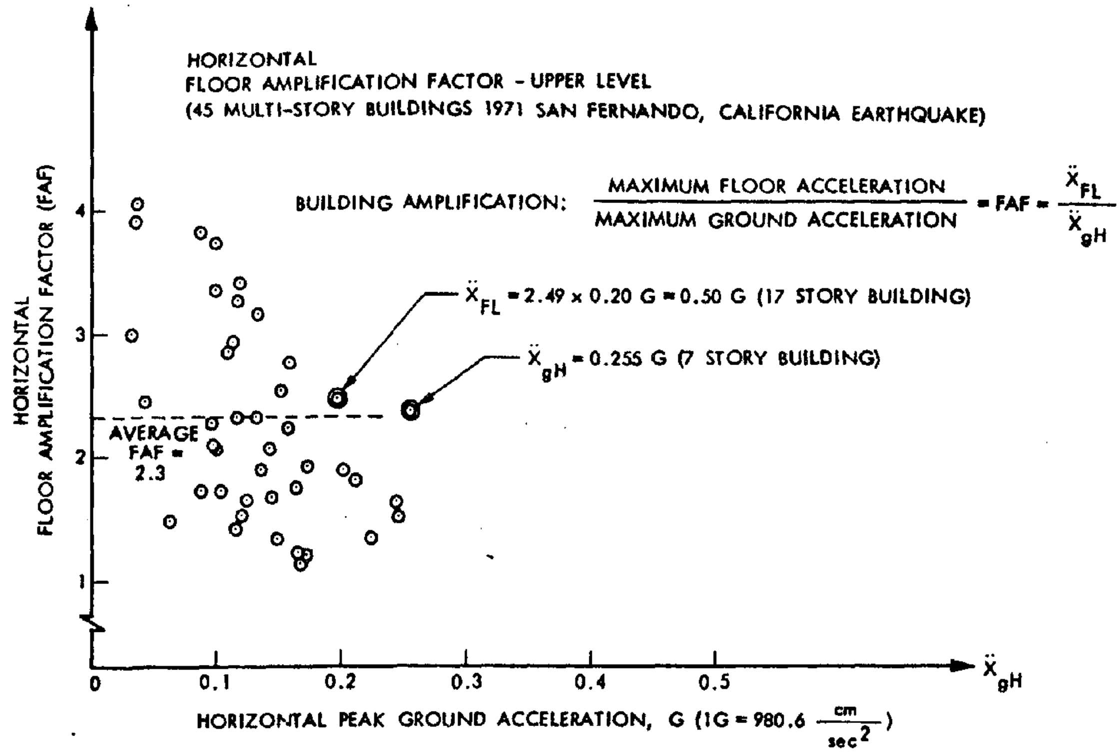

FIGURE 4. HORIZONTAL BUILDING AMPLIFICATION COMPARED TO PEAK GROUND MOTION.

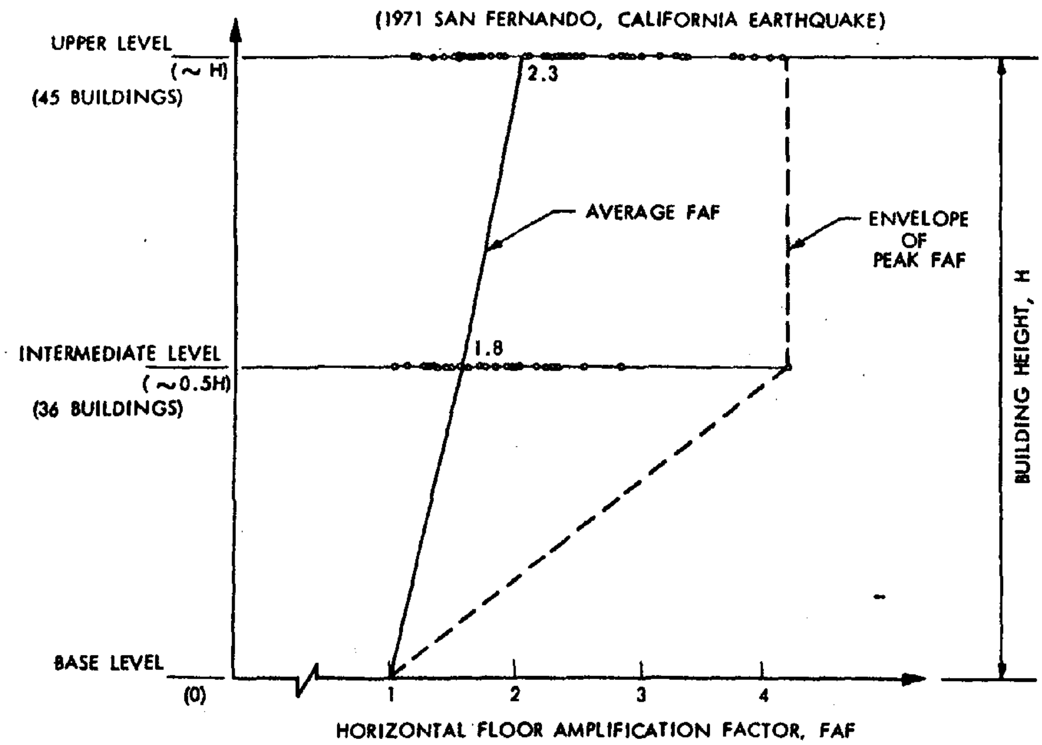

FIGURE 5. DISTRIBUTION OF HORIZONTAL BUILDING AMPLIFICATION OVER BUILDING HEIGHT.

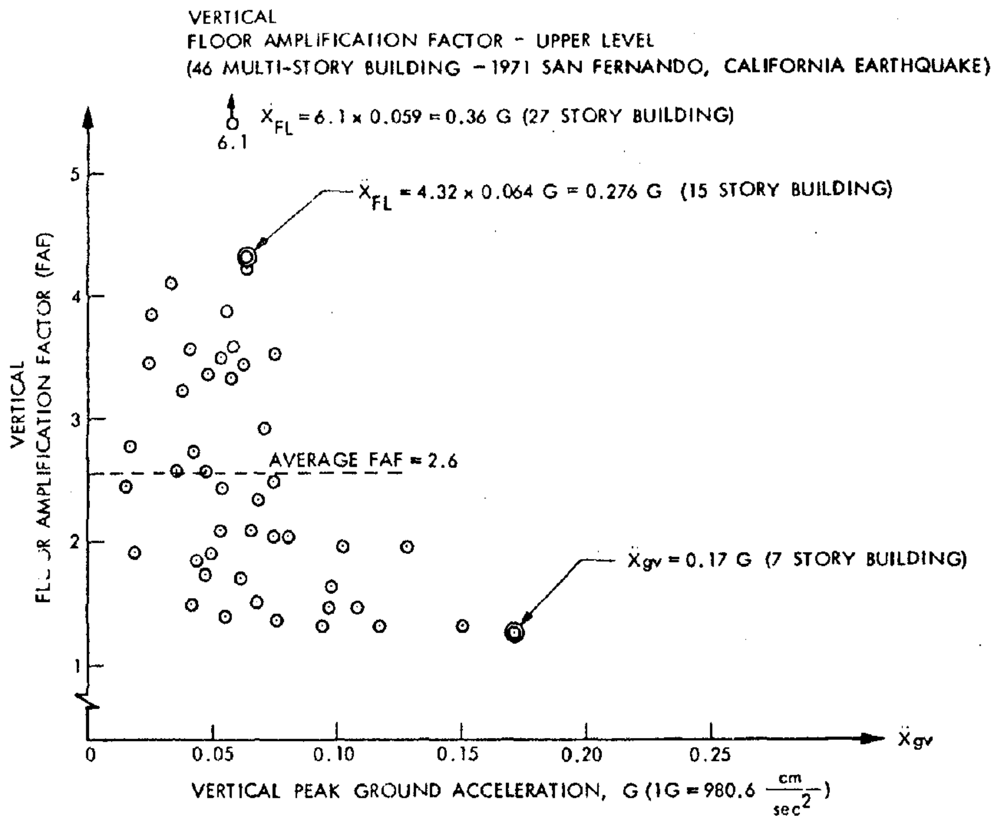

FIGURE 6. VERTICAL BUILDING AMPLIFICATION COMPARED TO PEAK GROUND MOTION.

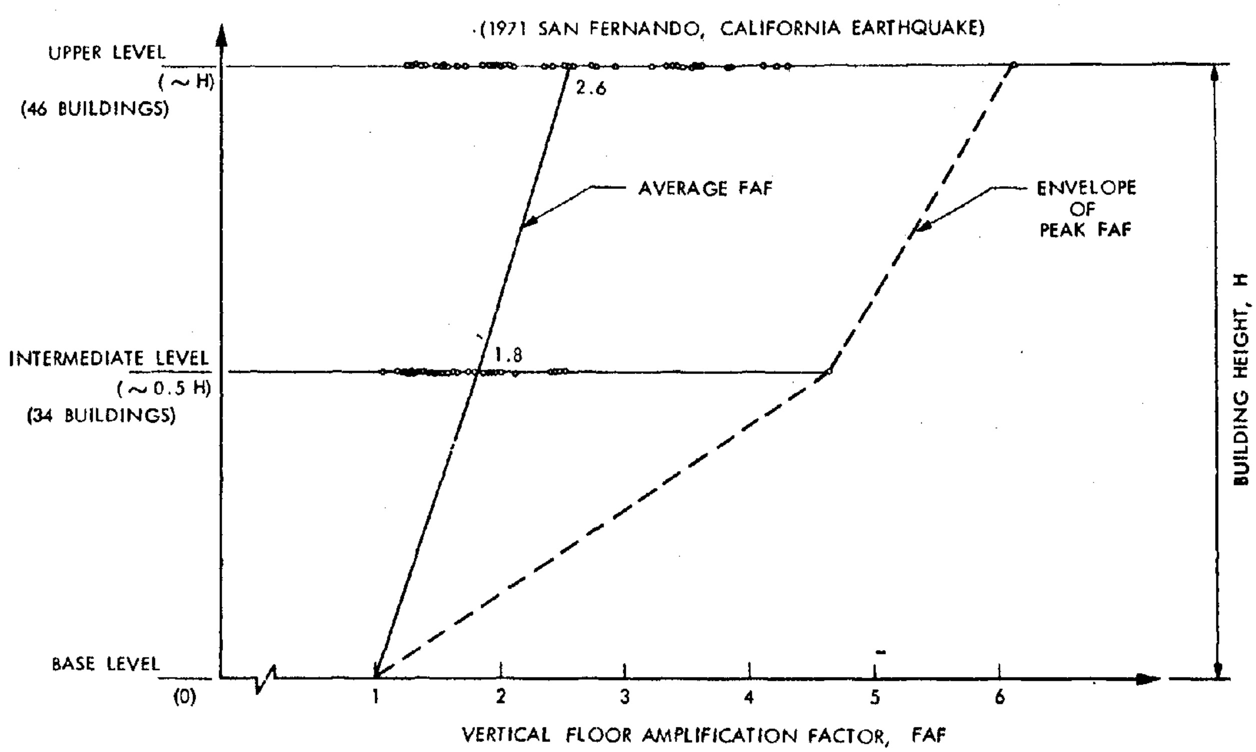

FIGURE 7. DISTRIBUTION OF VERTICAL BUILDING AMPLIFICATION OVER BUILDING HEIGHT.

ment acceleration to maximum ground acceleration, the computer (16) SMAF (Spring Mounted Amplification Factor) for the lateral response of spring isolated equipment with 1.0 in. static deflection mounts and equal vertical and horizontal stiffness are compared in Figure 8 for equipment located at the upper levels of a building. The range of upper level horizontal equipment response acceleration was 1.85 G to 0.123 G. Figure 9 compares the SMAF for equipment located at the base, intermediate, and upper levels of a building. The average amplification for a spring mounted equipment item was 3.3 at the base level, 5.0 at the intermediate level, and 6.2 at the upper level of the buildings with recorded motion.

BUILDING DRIFT

The response of structures (in terms of structural element stress) at earthquake levels which exceed the design capacity are mitigated by nonlinear behavior but at the expense of large yielding displacements or drifts. Often, drift is the cause of the majority of damage sustained by buildings during an earthquake. The review of actual recorded building motion provides a realistic estimation of building drifts which are the result of the ductile behavior of buildings during moderate earthquakes. Figure 10 gives the drift determined from recorded data (19) obtained from the example instrumented multi-story concrete frame building. The peak story drift for this example building was of the order of one inch or 0.01 foot drift per foot of building height which is in accordance with the observed (23) nonstructural damage resulting from the 1971 San Fernando earthquake. Estimates (25, 29) of approximate damage levels of drift for buildings during the San Fernando earthquake have been made for comparison of frame and shear wall construction performance. Studies (30, 31) have attempted to correlate the damage statistics gathered after the San Fernando earthquake, but definitive design criteria have not been developed which consider damage limitation due to drift.

ELEVATOR SYSTEMS

The vulnerability of building elevator systems to earthquake damage has been well documented in earthquake damage studies and reports (1,2,3). The damage statistics (over 674 inoperable) for elevator damage due to the 1971 San Fernando earthquake (2,8) provide an indication of the expected elevator damage that will occur when an earthquake of moderate magnitude occurs near a major metropolitan area. The occurrence of a large magnitude earthquake near an urban area would damage and impair an even greater number of building elevator systems due to the larger area experiencing significant ground motion. Regulatory code changes have been proposed and adopted by a few government plan check and review agencies to mitigate some of the past earthquake damage modes for new elevator construction. The question of retrofiting existing elevator systems has been discussed and a statewide code recently adopted. These codes require that equipment be anchored and that rails and support framing be designed to resist specific lateral forces. In addition, these codes include provisions for automatic controls which shutdown the elevators following an earthquake, after allowing passen-

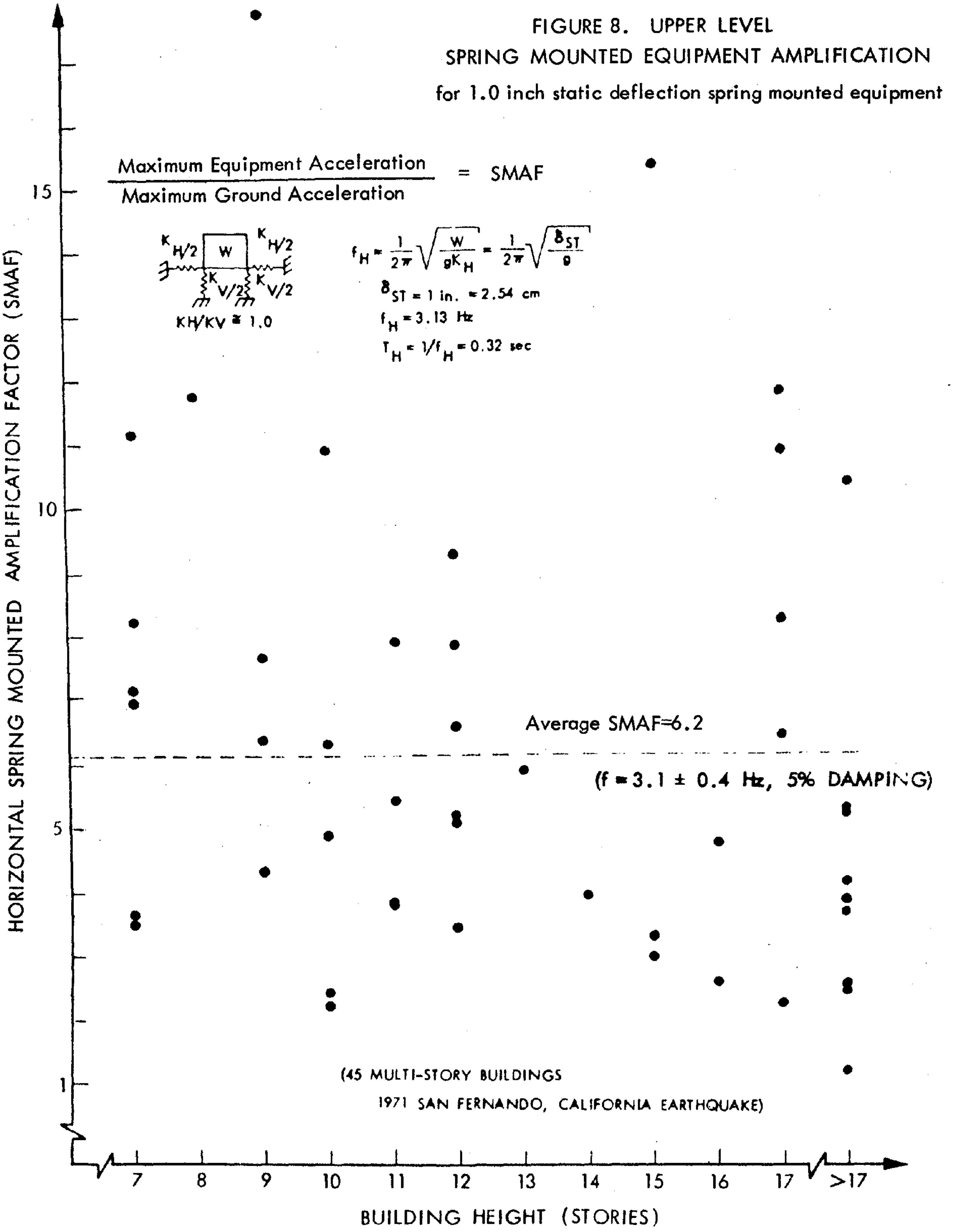
FIGURE 8. UPPER LEVEL
SPRING MOUNTED EQUIPMENT AMPLIFICATION
for 1.0 inch static deflection spring mounted equipment
Maximum Equipment Acceleration / Maximum Ground Acceleration = SMAF
W
KH/KV ≅ 1.0
δST = 1 in. = 2.54 cm
fH = 3.13 Hz
TH = 1/fH = 0.32 sec
Average SMAF=6.2
(f = 3.1 ± 0.4 Hz, 5% DAMPING)
(45 MULTI-STORY BUILDINGS
1971 SAN FERNANDO, CALIFORNIA EARTHQUAKE)
HORIZONTAL SPRING MOUNTED AMPLIFICATION FACTOR (SMAF)
BUILDING HEIGHT (STORIES)
1
5
10
15
7
8
9
10
11
12
13
14
15
16
17
>17

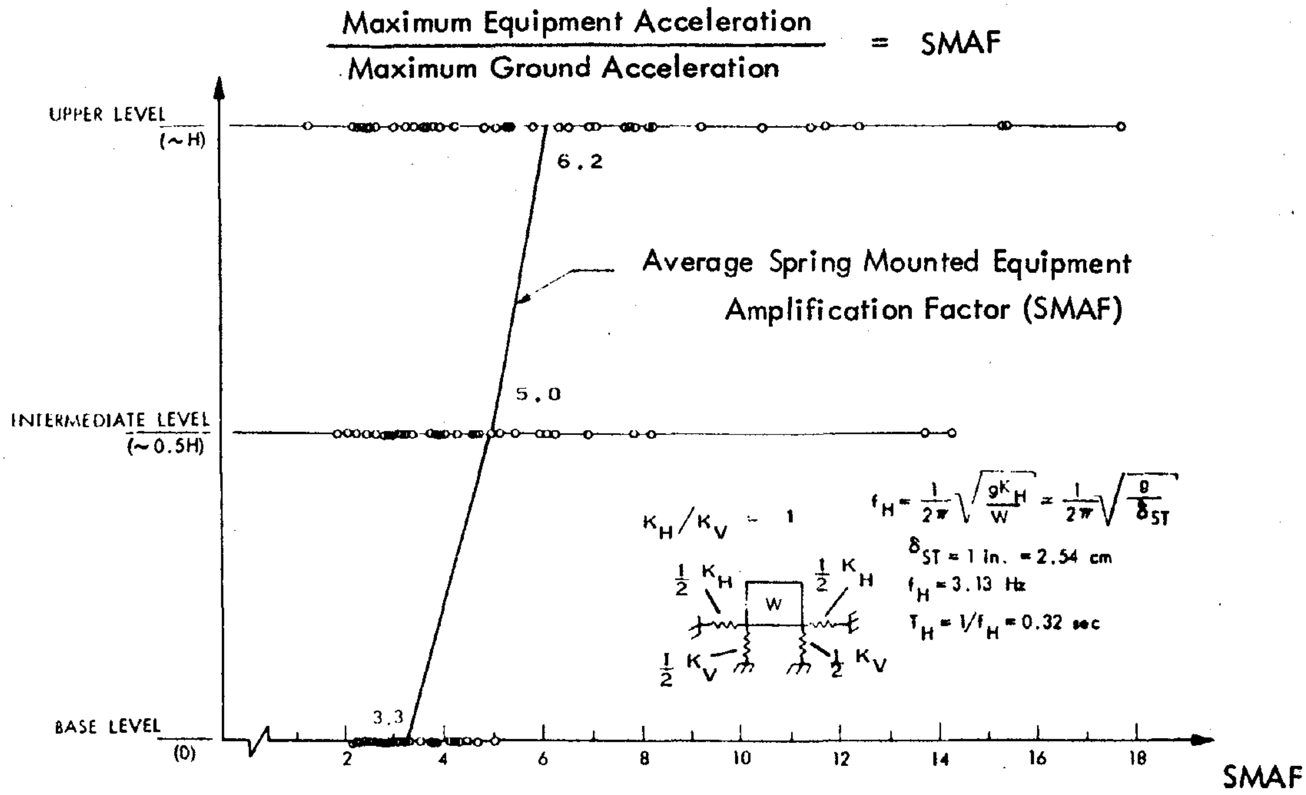

FIGURE 9. SPRING MOUNTED EQUIPMENT AMPLIFICATION

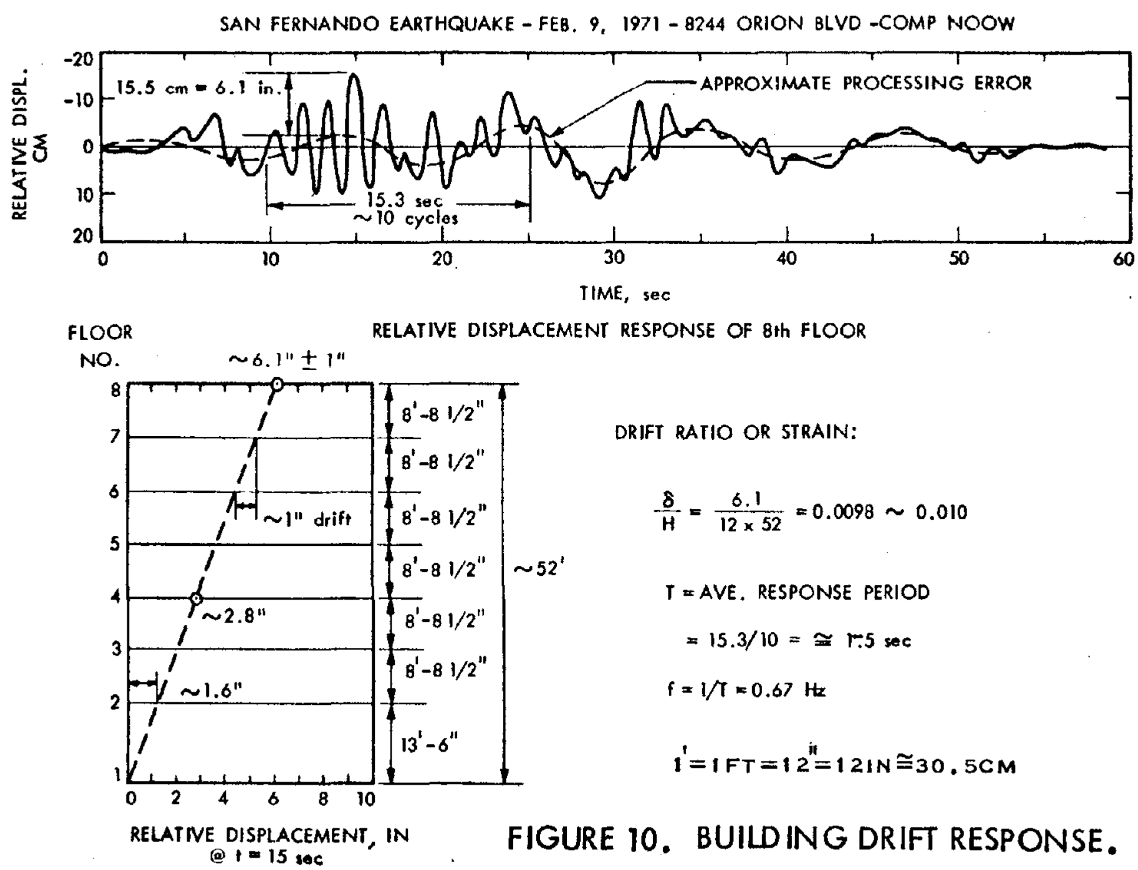

FIGURE 10. BUILDING DRIFT RESPONSE.

gers to exit at the nearest floor, and prevent use until inspection and repair occur. Thus, the purpose of these code requirements is to minimize physical elevator damage, and provide for shutdown of the elevators in the case of damage to prevent entrapment and further elevator damage.

However, the failure of elevators to operate after an earthquake has a more serious aspect than the loss of a means of egress for the occupants of buildings. Current Life-Safety Codes for high-rise buildings (greater than 75 feet in height) require that elevators, in the case of fire, operate under the control of the Fire Department. It is not practical to get people out of a large, tall building in emergencies, and current practice is to design places of refuge within the building where the occupants will be safe from fire. But the elevators must function so that fire rescue teams can have immediate access to the floors involved and must continue to function, even when the occupants are protected by firewalls and other emergency devices, to allow the necessary fire fighting and smoke removal equipment to be rapidly brought up to the floors as required. Thus, given the increased probability of fire following an earthquake, the elevator systems of a building are the "weak-link" of the Life Safety System of a modern high-rise building located in an earthquake prone area. Current elevator code provisions do not consider the necessity for functional requirements following an earthquake. A comprehensive review (34) of the current seismic design considerations for elevator systems is currently under preparation. The primary problem in elevator design, from a structural standpoint, is providing sufficient framing and anchor points within the hoistway to allow restraint (and adequate connections) for the car and counterweight rails.

MECHANICAL/ELECTRICAL SYSTEMS

The mechanical/electrical systems of a building are an extremely complex network of equipment and distribution of required services. The level of detailing for these systems contained within the construction documents has, in the past, been minimal. The construction drawings are schematic with great emphasis placed upon the written specifications. Thus, the requirement of seismic details on mechanical and electrical drawings for California hospital construction caused some initial confusion among designers. The development of guidelines and acceptable common details (33) greatly eased this problem (see Figure 11). A more comprehensive set of guidelines (34) (and commentary) is currently under development. It is anticipated that these guidelines will greatly simplify the seismic design of mechanical/electrical systems within all buildings. The mechanical/electrical service systems of a building may be logically identified as:

Mechanical Systems
- HVAC
- Plumbing
- Fire Protection

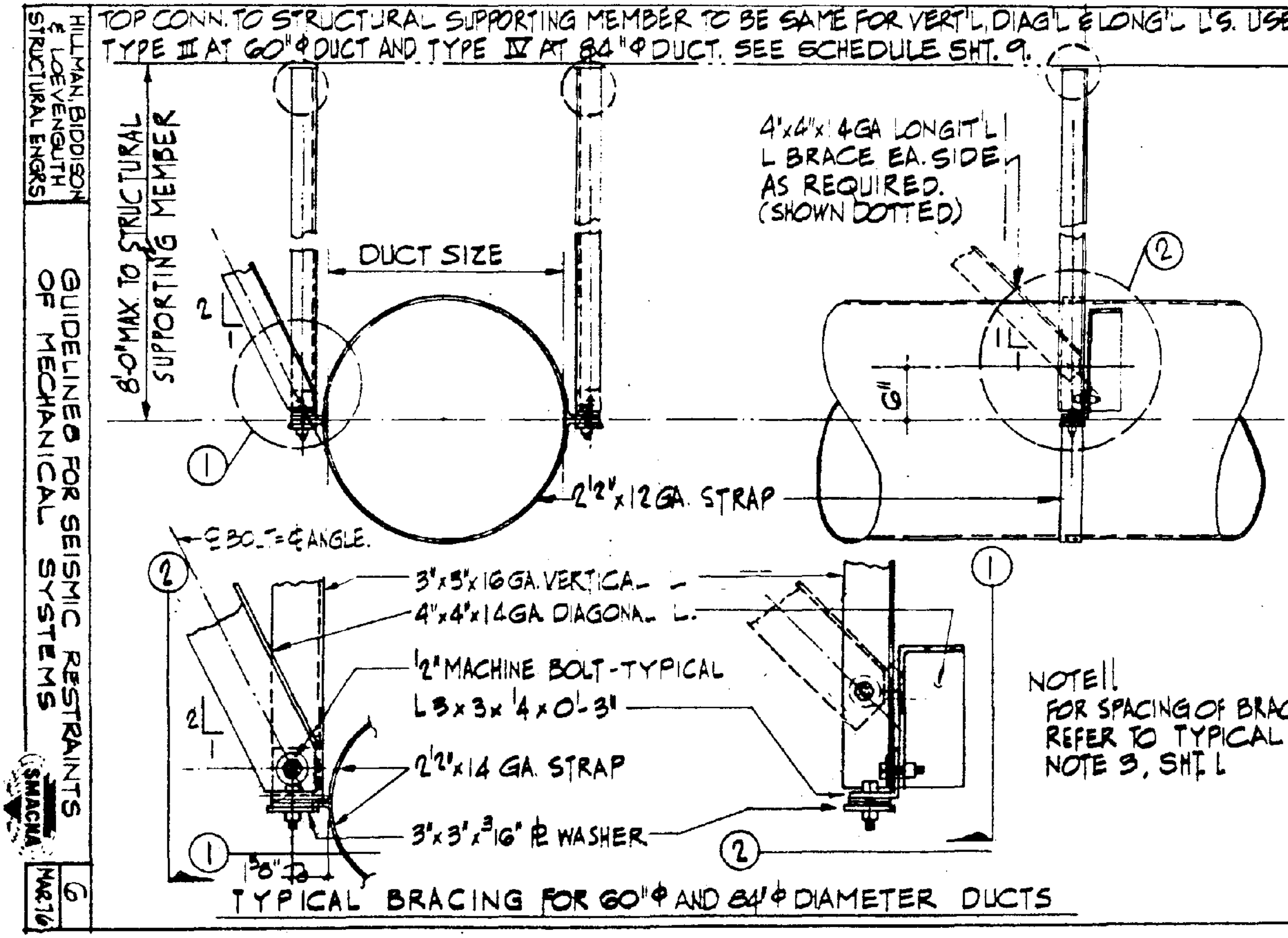

FIGURE 11. EXAMPLE GUIDELINE DETAIL (REF. 33)

Electrical Systems
Power
Lighting
Communication and Signal

Life-Safety Systems

These systems are basically equipment systems. Equipment components may be classified as either rigid or flexible. Anchored rigid equipment transfers the inertial (acceleration) forces directly to the anchor points. As discussed previously, a study of the recorded building motion obtained during the 1971 San Fernando earthquake from a sample 49 instrumented high-rise buildings indicates that amplification factors which range from 2 to 4 should be expected for peak horizontal and vertical floor accelerations in the upper levels of a multi-story building. For base mounted equipment, the anchor points must resist the combined effects of both base shear and overturning forces. In determining the overturning moment, the effect of vertical accelerations must be considered.

While an insert anchor can be installed which will resist such forces, the connection of an anchor bracket to a minimum gage sheet metal enclosure can be difficult and require localized stiffening. This problem can be avoided by restraining the equipment at the top by a diagonal brace or wall attachment. However, a diagonal brace requires additional clearance adjacent to the equipment and, if wall or partition attachment is considered, a nonstructural partition will not be capable of sustaining a large attachment force.

A vast majority of mechanical equipment within a building is supported on vibration isolation mounts to eliminate noise transmission through the structure. All major manufacturers of vibration mounting offer an "earthquake mount" or "earthquake snubber" restraints which prevent overstress of spring mounts. Numerous articles and design details on this subject are available (8, 33); most have been published in trade magazines.

The support of tanks must be carefully considered, particularly vertical tanks on legs.

Mechanical service systems require extensive piping systems. It has been generally observed that piping systems within a building sustain little damage despite significant structural and nonstructural damage suffered by the building due to an earthquake. Earthquake damage to piping systems, when damage occurs, is caused by excessive pipe movement and differential deflection between piping and connected equipment. Few pipes are actually broken or sheared; most failures occur at fittings. Often failures occur due to excessive swaying of long pipe runs flexing smaller intersecting branch lines or short vertical risers which are clamped to the structure. Ordinary piping systems are suspended from floor slabs with vertical hangers which, in effect, forms a pendulous system. The frequency of this effective system is quite low which essentially isolates the piping system from lateral inertial forces. This flexibility, which is due to pendular behavior, accounts for both the few instances of failure and the failures due to excessive displacements. Fire sprinkler systems are the only piping which in the past have been designed to resist earthquake loading. Due to the few instances of damage to fire-sprinkler piping caused by earthquake, it is often suggested that all major piping within a building be braced in the same manner as sprinkler piping. Another criteria utilized is to place braces at intervals such that the piping system moves with the slab from which it is suspended. This practice, required by code in some instances, is highly controversial since problems with noise transmission and thermal expansion arise. A more reasonable criteria would be to provide bracing only at points which would prevent the type of piping failures which have been noted in earthquake damage surveys. This would require restraining pipe runs in order to prevent overstress of branch lines or where piping changes direction and passes through a fire-wall. Attention should also be given to the manner in which the pipe riser weight is supported vertically. The above comments on piping apply also to ductwork and conduit. Ducts must be prevented from excessive swaying which can damage ceiling support systems. The crossing of building seismic joints by piping, ductwork, and conduit should be, in general, avoided.

Lighting fixtures must be properly secured to the structure or architectural components.

Recessed light fixtures which are supported by exposed T-bar ceiling systems are potential personnel hazards. Each fixture must have at least two independent hanger wires per fixture at diagonal corners which are anchored to the floor slab above. Pendant-hung fixtures require design attention for the specification of swivel ceiling support and fixture bottom support details to limit pendant swing. The positive attachment of battery powered emergency lighting to the structure is often neglected in building design specifications.

Electrical distribution and motor control equipment is usually placed within sheet metal enclosures. The specification and anchoring of such equipment requires careful attention. Often, the most significant source of flexibility in equipment enclosures is due to local deformation of the equipment base near the anchor points.

Communication systems require careful consideration of power sources required for function. For example, digital dialing (pushbutton) phones require an external AC power source for function. If function of intrabuilding communications is necessary during an emergency, then a battery/inverter system should be considered to supply the required AC power.

Elements of the life-safety systems such as emergency power, emergency lighting, alarm systems, and smoke removal systems require concentrated attention during the design process. These systems must be secure and functional after a major earthquake. Emergency battery rack failures are one of the most common observations in post-earthquake studies, yet the cost for strengthening and securing such racks are minimal. Evaluation of equipment subjected to dynamic environments require consideration of operational and functional aspects as well as structural or enclosure strength. Unless specific requirements have been included in equipment procurement specifications, the ability of equipment to survive a dynamic environment, such as the building response to an earthquake, will be quite uncertain.

ARCHITECTURAL SYSTEMS

A primary function of architectural systems is to enclose and subdivide the interior space of a building. A wide variety of enclosure and finish systems are utilized within the building construction industry. Nonstructural architectural components which have floor-to-floor connection such as slab-to-slab partitions (fire-walls), curtain walls, and stairs must accommodate story drifts or be damaged by the imposed forces. Exterior and interior glazing, doors, and hung ceilings, while normally not directly connected between floors, must accommodate the deformation imposed by the exterior panels or interior partitions. The cost of repairing plaster, drywall, glass, and other drift damage is often the most costly post-earthquake repair item due to the labor man-hours required. Often, the mode of interaction between the enclosure or finish system and the primary structure is not apparent. Research (25, 29) is continuing in the identification and recommended detailing required to accommodate such interaction. Design guidelines and acceptable architectural details (10) within hospitals are currently under preparation.

The critical design parameter for architectural systems is the inter-story drift expected during a moderate earthquake; not the drift determined from application of design lateral forces required by code. Racking tests (26, 27) of various types of interior partitions have indicated that incipient damage, in terms of inter-story drift, begins at about 0.0025 times the story height. Inter-story drifts that would require repair to the partitions would be in the range of 0.005 to 0.010 times the story height. These values are in general accordance with the observed damage (29) resulting from the San Fernando earthquake. In a building which has not been specifically designed to limit excessive seismic drift damage, little can be done to prevent such damage. An understanding of the structural behavior of a building during moderate earthquakes is necessary. The question of how much drift allowance to provide in the detailing of architectural components must be decided upon by the architect in consultation with his structural engineer. Cost tradeoff studies are necessary to determine whether construction dollars should be placed in increased structural resistance (stiffness) or architectural details which allow for drift.

Suspended ceilings which are hung with wire, and yet attached to a partition at the room periphery, will accommodate drift. However, the presence of knee braces (extended metal studs) in long walls and the occurence of firewalls will retard this flexibility in some areas. Some peripheral damage will occur either by buckling or tearing away of the suspended ceiling. In order to prevent ceiling collapse, additional wire hangers should be provided, especially at the periphery of rooms and corridors. Recommendations which suggest that diagonal crossbracing wires be used to insure that ceilings remain rigid and move with the above slab require that the peripheral details of such installations accommodate the drift or simply be a covered gap.

The behavior of stairs within an enclosed stairwell which is distorted by building drift is critical. Stairs tend to act as diagonal bracing between floors, and can have damaging loads induced in them by inter-story deflections. Hence effective provisions to free them must be made. One solution is to design stairs as two flight or three flight free-standing staircases, spanning from the floor above to the floor below as a self contained structure, without any outside support to the landing. The flexibility for inter-story movement at right angles to the main flights must be checked. Another arrangement is to put a separation gap through the mid-story height landing, so that each half of the landing is connected to only one flight of stairs. The support for the vertical load of the landing is arranged so that the landing is free to move laterally. Such support can be by flexible hangers, flexible struts or sliding support on a beam. Where a stairway consists of single flights between floors, each flight can be fixed at one end by a movement gap and sliding support, or freed at the top end by providing flexible strut support. Separation gaps can be covered by metal plates with provision for sliding.

Interior partitions and fire rated walls which have floor-to-floor connection require careful design consideration if drift damage is to be minimized. For flexible frame structures, the allowance of sufficient drift clearance between the structural frame and interior non-structural walls is necessary. The development of economic details which support non-structural walls against out-of-plane seismic forces, yet allow freedom for interstory drift in the plane of the walls, is an architectural design challenge. Problem areas are corners and tee-junctions of walls as well as the junction of walls with columns. The selection of compressable filler material for the clearance gaps which will meet fire and/or acoustic requirements is another problem to be resolved.

If the nonstructural walls are not decoupled from the structure, then damage is unavoidable. Given a conscious design decision has been made to "sacrifice" the nonstructural walls for severe earthquakes, then the detailing of door frames which provide building egress, or access through firewall partitions and structural walls must be carefully considered to insure that doors are not jammed shut by drift imposed forces.

The proper detailing of exterior enclosure systems, and connections for architectural precast panels, stone veneer, and sheet metal panels are areas which require design attention. A "good" anchor connection is one which can develop considerable ductility without sudden or brittle failure for loading beyond the design level (or code allowable stress level). Considerable design effort in these areas has been expended for the design of individual large buildings, but little formal documentation can be found in the published literature. Commercial glazing details usually accommodate drift imposed frame distortion if sufficient edge clearance (1/4 inch) is maintained between the glass frame. Flexible sealants or rubber seals allow the glass to rotate within the frame to provide additional frame distortion without imposing a diagonal force into the glass.

The design of frame structures with masonry infill walls or other types of nonstructural infill panels which act as a shear diaphram is an area of concern for structural engineers. Such walls affect the strength of reinforced concrete frames and must be included in the structural analysis and design. Recent earthquake damage has identified (3, 7) the problems of masonry infill wall construction. Properly reinforced infill panels can provide a controlled damage mechanism for the structure. Procedures and design recommendations for such construction are available in the literature (28, 36).

BUILDING CONTENTS

Free-standing equipment is susceptible to sliding or overturning due to floor motion. Since coefficients of friction vary widely, static friction cannot be relied upon to restrain equipment and supplies. Experience has indicated that furniture, cabinets and unanchored equipment within a building can undergo considerable displacement during an earthquake, especially in the upper levels of a building. Large, rigid architectural components, such as heavy artwork, heavy fixtures, shading devices, etc., must be anchored to the structure. The architect should provide recommendations to the owner for the restraint of heavy furnishings. Face bars on shelves are suggested. It should be noted that overhead mutual bracing of shelves and cabinets is an expedient means of preventing tip-over. The attachment of shelving and cabinets to drywall partitions with toggle bolts is acceptable for lightly loaded shelves. For heavy shelving, positive attachment should be provided to the partition studs. Often, the distribution of weight on shelving is overlooked; heavy or fragile items should be located in the lower half of the shelf. A comprehensive study outlining restraint of hospital equipment, furniture, and supplies has been prepared (35).

CONCLUSIONS AND RECOMMENDATIONS

The review of documented past earthquake damage provides the necessary background and understanding of the problem. The primary references (1-7) should be standard reference material within all architectural offices and schools.

Building nonstructural design professionals need an understanding of actual building response during a moderately severe earthquake to understand the limitations of code static force coefficients. An understanding of building response to earthquake ground motion is necessary for nonstructural designers to prepare specifications for equipment manufacturers and suppliers. The proper design of equipment anchorage and the interconnection of nonstructural components within a building requires knowledge of the magnitude of the forces induced in equipment and the deformations imposed upon the components. The lateral force coefficients included in recent code requirements for anchorage of nonstructural elements are realistic approximations of the induced force levels to be expected in a moderate earthquake.

Realistic inter-story drift allowances should be established for detailing of architectural systems. Architectural designers need accepted drift criteria, consistent with structure types (i.e, frame, shear wall, box, etc.), so that adequate attention can be devoted to seismic design during conceptual design development. It is suggested that a story drift allowance of 0.010 times the story height be considered for design of clearances between the structural frame and nonstructural elements.

As the leader of the design team, the architect controls the level of design effort given to the seismic consideration of nonstructural components of buildings. The architect has the initial responsibility of advising the client of the necessity for considering the seismic design of nonstructural components within the proposed building. This must be done at the earliest possible time to insure that the costs for such considerations are included in the preliminary cost estimates. The architect must then insure that all nonstructural components (architectural, mechanical, electrical, elevator) are detailed on the drawings or carefully described in the specifications. The architect must lead the design team to defend these details from contractor proposed alternates that do not meet the design intent, and insure that they are properly executed in the field.

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APPENDIX

TABLE 1: Extract from Title 17, Safety of Construction of Hospital, State of California

(L) Lateral Forces on Non-Structural Components.

Architectural, mechanical and electrical components and systems in hospital buildings, essential equipment necessary for the complete functioning of the hospital operations and critical components located outside of buildings shall be anchored for lateral forces in accordance with Section 2312(g), formula (12-8) and the exception thereto, where Cp in Table No. T17-23-J is less than 1.0 the product of IS need not exceed 1.5. The values of Cp for the anchorage of architectural, mechanical and electrical components and systems in buildings and critical components outside of buildings shall be as set forth in Table No. 23-J and Table T17-23-J.

Where the provisions of these tables do not specify Cp values for the anchorage of particular components which in the opinion of the Office of the State Architect should be anchored to resist lateral forces for the safety of the occupants, the office may assign Cp coefficients with the advice of the architect or engineer based on coefficients specified for similar components listed in these provisions.

The design of mechanical and electrical equipment, machinery, cabinets, etc., and the provisions incorporated in its manufacture for anchorage to supports or connection to seismic restraints should provide for these same lateral forces. However, the Office of the State Architect will not review the design or construction of such manufactured items except for their anchorage to the building structure or to a supporting foundation.

TABLE NO. T17-23-J
Horizontal Force Factor "C_p" for Elements of Structures and for Anchorage of Non-structural Components

Category	Direction of Force	Value of C_p [1]
1. Interior nonbearing walls and partitions over 5 feet in height	Normal to flat surface	0.20
2. When not part of a building and over 5 feet in height, masonry of concrete fences and walls	Normal to flat surface	0.20
3. When part of a building, cantilever walls above the ground floor (except parapets)	Normal to flat surface	0.30

TABLE NO. T17-23-J
(Con't)

4.	Penthouses (except where framed by an extension of the building space frame)	any horizontal direction	0.20
5.	When connected to, part of, or housed within a building:		
	(a) Storage racks with the upper storage level more than 5 feet in height (plus contents)	any horizontal direction	0.20 [2,4]
	(b) Floor supported cabinets, files, and bookstacks more than 5 feet in height (plus contents)	any horizontal direction	0.20 [2,4]
	(c) Wall hung cabinets, shelving, and television racks (plus contents)	any horizontal direction	0.20 [2,4]
	(d) Suspended or surface mounted light fixtures [5]	any horizontal direction	1.00
	(e) Piping, electrical conduit, cable trays, and air handling ducts: [3]		
	(1) Rigidly supported	any horizontal direction	0.33 [4]
	(2) Flexibly supported	any horizontal direction	1.00 [4,6]
	(f) Equipment and machinery such as boilers, chillers, pumps, tanks, cooling towers, engines, generators, motors, air handling units, transformers, switchgear, and control panels:		
	(1) Rigidly supported (fundamental period of vibration of equipment with its supports less than 0.05 seconds)	any horizontal direction	0.33 [4]
	(2) Flexible or flexibly supported	any horizontal direction	1.00 [4,6]
	(g) Hospital equipment permanently attached to building utility services such as: surgical, morgue and recovery room fixtures, radiology equipment, food service fixtures, and laboratory equipment.	any horizontal direction	0.20 [4]

TABLE NO. T17-23-J
(Con't)

(h) Communication equipment and emergency power equipment such as motor generators, battery racks, and fuel tanks necessary for the operation of such equipment [7]	any horizontal direction	1.00 [4]
6. Power-cable driven elevators or hydraulic elevators with lifts over 5 feet:		
(a) Car and counterweight guides, guide rails and supporting brackets and framing.	any direction	0.33 [8]
(b) Driving machinery operating devices and control equipment:		
(1) Rigidly mounted	any direction	0.33 [4]
(2) Flexibly mounted (a fundamental period of vibration of the installation greater than 0.05 seconds)	any direction	1.00 [4,6]

Footnotes

1. Cp shall be not less than the ratio of Fx/Wx for floor or roof level under consideration. Where a dynamic analysis is used in the design of the building, the forces so determined may be used in the design of the elements or components with appropriate resistance criteria. Where a dynamic analysis is not used the minimum Cp values given should provide reasonable protection, but the use of higher Cp values is suggested for unusually important or expensive equipment or for equipment located in the upper levels of multistory buildings. See Section 2312 (g) and Section T17-2312 (e) for maximum values of the product of IS in formula (12-8).

2. Wp for storage racks, cabinets and bookstacks shall be the weight of the racks plus contents. The value of Cp for storage racks over two storage support levels in height shall be 0.16 for the levels below the top two levels.

3. Seismic restraints may be omitted from the following installations:

   (a) Gas piping less than 1 inch inside diameter

   (b) Piping in boiler and mechanical equipment rooms less than 1¼ inch inside diameter.

TABLE NO. T17-23-J
(Con't)

(c) All other piping less than 2½ inch inside diameter.

(d) All piping suspended by individual hangers 12 inches or less in length from the top of pipe to the bottom of the support for the hanger.

(e) All electrical conduit less than 2½ inch inside diameter

(f) All rectangular air handling ducts less than 6 square feet in cross sectional area.

(g) All round air handling ducts less than 23 inches in diameter.

(h) All ducts suspended by hangers 12 inches or less in length from the top of the duct to the bottom of the support for the hanger.

4. The component anchorage shall be designed for the horizontal "Cp" force acting simultaneously with a vertical seismic force taken as one third of the horizontal "Cp" value used.

5. Suspension systems for light fixtures which have passed shaking table tests approved by the Office of the State Architect of which, as installed are free to swing a minimum of 45° from the vertical in all directions shall be assumed to comply with the lateral force requirements of Section T17-2312 (L).

   Unless of the cable type, free swinging suspension systems shall have a safety wire or cable attached to the fixture and structure at each support capable of supporting 4 times the support load.

6. Because of the possibility of resonant response of flexible equipment systems in the upper stories and roofs of buildings, consideration should be given to the use of higher values of Cp when the predominant period of response of structure and equipment systems are the same or nearly the same. Under the situation values of Cp twice as large as those indicated above are suggested.

7. Emergency equipment should be located where there is the least likelihood of damage due to earthquake. Such equipment should be located at ground level and where it can be easily maintained to assure its operation during an emergency.

8. Wp for elevator cars shall be the weight of the car plus 0.4 times its rated load. The lateral forces acting on guide rails shall be assumed to be distributed 1/3 to the top guide rollers and 2/3 to the bottom guide rollers of elevator cars and counter weights.

(g) **Lateral Force on Elements of Structures.** Parts or portions of structures and their anchorage shall be designed for lateral forces in accordance with the following formula:

$$F_p = ZIC_pSW_p \;\ldots\ldots\ldots\ldots\ldots\; (12\text{-}8)$$

EXCEPTION: Where C_p in Table No. 23-J is 1.0 or more the value of I and S need not exceed 1.0.

The distribution of these forces shall be according to the gravity loads pertaining thereto.

(h) **Drift and Building Separations.** Lateral deflections or drift of a story relative to its adjacent stories shall not exceed 0.005 times the story height unless it can be demonstrated that greater drift can be tolerated. The displacement calculated from the application of the required lateral forces shall be multiplied by $(1.0/K)$ to obtain the drift. The ratio $(1.0/K)$ shall be not less than 1.0.

All portions of structures shall be designed and constructed to act as an integral unit in resisting horizontal forces unless separated structurally by a distance sufficient to avoid contact under deflection from seismic action or wind forces.

TABLE NO. 23-K
VALUES FOR OCCUPANCY IMPORTANCE FACTOR I

TYPE OF OCCUPANCY	I
Essential Facilities[1]	1.5
Any building where the primary occupancy is for assembly use for more than 300 persons (in one room)	1.25
All others	1.0

[1]See Section 2312 (k) for definition and additional requirements for essential facilities.

TABLE NO. 23-J—HORIZONTAL FORCE FACTOR "C_p" FOR ELEMENTS OF STRUCTURES

PART OR PORTION OF BUILDINGS	DIRECTION OF FORCE	VALUE OF C_p
1. Exterior bearing and nonbearing walls, interior bearing walls and partitions, interior nonbearing walls and partitions. Masonry or concrete fences	Normal to flat surface	0.20
2. Cantilever parapet	Normal to flat surface	1.00
3. Exterior and interior ornamentations and appendages.	Any direction	1.00
4. When connected to, part of, or housed within a building: a. Towers, tanks, towers and tanks plus contents, chimneys, smokestacks and penthouse	Any direction	0.20[2]
b. Storage racks with the upper storage level at more than 8 feet in height plus contents		0.20[2,3]
c. Equipment or machinery not required for life safety systems or for continued operations of essential facilities		0.20[2,4]
d. Equipment or machinery required for life safety systems or for continued operation of essential facilities		0.50[4,5]
5. When resting on the ground, tank plus effective mass of its contents.	Any direction	0.12
6. Suspended ceiling framing systems (Applies to Seismic Zones Nos. 2, 3 and 4 only)	Any direction	0.20[6]
7. Floors and roofs acting as diaphragms	Any direction	0.12[7]
8. Connections for exterior panels or for elements complying with Section 2312 (j) 3C.	Any direction	2.00
9. Connections for prefabricated structural elements other than walls, with force applied at center of gravity of assembly	Any direction	0.30[8]

[1]See also Section 2309 (b) for minimum load on deflection criteria for interior partitions.

[2]When located in the upper portion of any building where the h_n/D ratio is five-to-one or greater the value shall be increased by 50 percent.

[3]W_p for storage racks shall be the weight of the racks plus contents. The value of C_p for racks over two storage support levels in height shall be 0.16 for the levels below the top two levels. In lieu of the tabulated values steel storage racks may be designed in accordance with U.B.C. Standard No. 27-11.

Where a number of storage rack units are interconnected so that there are a minimum of four vertical elements in each direction on each column line designed to resist horizontal forces, the design coefficients may be as for a building with K values from Table No. 23-I, $CS = 0.20$ for use in the formula $V = ZIKCSW$ and W equal to the total dead load plus 50 percent of the rack rated capacity. Where the design and rack configurations are in accordance with this paragraph the design provisions in U.B.C. Standard No. 27-11 do not apply.

[4]For flexible and flexibly mounted equipment and machinery, the appropriate values of C_p shall be determined with consideration given to both the dynamic properties of the equipment and machinery and to the building or structure in which it is placed but shall not be less than the listed values. The design of the equipment and machinery and their anchorage is an integral part of the design and specification of such equipment and machinery.

[5]For Essential Facilities and life safety systems, the design and detailing of equipment which must remain in place and be functional following a major earthquake shall consider drifts in accordance with Section 2312 (k). The product of IS need not exceed 1.5.

[6]Ceiling weight shall include all light fixtures and other equipment which are laterally supported by the ceiling. For purposes of determining the lateral force, a ceiling weight of not less than 4 pounds per square foot shall be used.

[7]Floors and roofs acting as diaphragms shall be designed for a minimum force resulting from a C_p of 0.12 applied to w_x unless a greater force results from the distribution of lateral forces in accordance with Section 2312 (e).

[8]The W_p shall include 25 percent of the floor live load in storage and warehouse occupancies.

SEISMIC BUILDING CODE DEVELOPMENT

Edwin G. Zacher

CONTENTS

SEISMIC BUILDING CODE DEVELOPMENT

INTRODUCTION

I will review briefly the history of seismic codes and of the role of professional organizations in seismic code activities. The history is probably incomplete but will indicate the involvement of the professions in this area.

SEISMIC CODE BEGINNINGS

The 1906 San Francisco earthquake focused the attention of the public and the design professions on the problem of providing seismic force resistance. A number of steel frame structures performed well in this temblor. These structures had been designed with good wind bracing systems, often for higher than minimum wind loads. Based on this, designing for 30 pound wind loads became the standard seismic load requirement.

The 1925 Santa Barbara earthquake caused a renewed interest in seismic resistant design and code provisions.[1] Specific code provisions for seismic design of structures in the United States began in 1927 when an optional appendix to the first edition of the Uniform Building Code was presented. These provisions were similar to the ordinance adopted by the City of Santa Barbara, California after the 1925 earthquake. The design provisions used the concept of lateral earthquake forces proportional to 10% of the dead load and live load (greater than 50 lbs./sq. ft.) for soil bearings less than 4000 lbs./sq. ft. and 7% for soils of 4000 lbs./sq.ft. and greater. Foundations were also to be inter-connected.

The first Code activity by professional associations for which records have been found was a statewide committee under the auspices of the California State Chamber of Commerce. This committee had representation from the San Francisco and Los Angeles (Northern and Southern) Sections of the ASCE, the Southern and Northern California Chapters of the AIA, the Pacific Coast Building Officials Conference, the Southern California Chapter of the AGC and the General Contractors of San Francisco, Inc.

The California State Chamber of Commerce Committee was organized in 1928 and published their code in 1939.[2] The published code was never adopted by any jurisdiction, but the provisions of the Code were incorporated in the Uniform Building Code and in Appendix A (later Title 21), the California State Code on school construction. The committee was also instrumental in obtaining passage of the Riley Act, which required seismic design of commercial and industrial structures in California.

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The U.S. Coast and Geodetic Survey began, in 1932, a strong motion accelerograph recording program. The 1933 Long Beach earthquake, and strong motion records obtained therefrom, led to the first mandatory seismic code provisions in the United States. On May 26, 1933, California Legislature passed the Riley Act which required design and construction to resist wind loads, or seismic forces based on a design coefficient of 2% of the design vertical load (approximately 2½% of the dead load). The Field Act covering public schools was enacted at this same time. This Act required inspection during construction, and forces for lateral design of from 6 to 10% of the vertical load for buildings less than three stories and 2 to 6% for buildings over three stories having moment resisting frames.

Some cities in California increased this seismic coefficient of 2% to higher values. The City of Los Angeles used a coefficient of 8% of the dead loads and one-half of the live loads, with schools increased to 10%. These same values were used in the Uniform Building Code of 1935 but modified so that when soils of less than 2000 lbs./sq. ft. to define firm soils with only a 50% increase of lateral load required for softer soils or buildings supported on piles.

In 1943, City of Los Angeles used a new coefficient which considered building flexibility and dropped the soils provision.(3) Further, buildings were still to conform to a 1911 Ordinance requiring that buildings could not exceed 13 stories in height. These same provisions were adopted into the 1949 UBC along with the incorporation of the first seismic risk map for the United States (based on past earthquake intensities).

LATER CODE DEVELOPMENTS

There appears to have been a hiatus of activity by the professional associations during the World War II years, then in 1947 an Advisory Committee on Engineering Seismology was formed. This committee had representatives from the San Francisco, Los Angeles and Seattle Sections of ASCE, the Structural Engineers Association of California (SEAOC), the Structural Engineers Association of Northern and Southern California (SEAONC, SEAOSC), the California Council of Architects, University of California, Stanford University, California Institute of Technology, California State Division of Architecture, City and County of San Francisco, Los Angeles County Regional Planning Commission, Seismological Society of America, U.S. Bureau of Reclamation, Southern Pacific Division of the U. S. Army Engineers and the Office of Naval Research. This advisory committee provided a liaison between the scientific and academic world and the practicing engineer in making seismic instrumental data available in a usable form.

The Seismology Committee (Lateral Froces Committee) of SEAONC originated as a Committee on Design for Wind and Earthquake Forces for the "Proposed New Building Code for the City of San Francisco" in 1946. The Joint Committee on Lateral Forces (ASCE-SF & SEAONC) was formed April 2, 1948. This distinguished committee (Arthur W. Anderson, John A. Blume, Henry J. Degenkolb, Harold B. Hammill, Edward M. Knapik, Henry L. Marchand, Henry C. Powers, John E. Rinne, George A. Sedgwick and Harold O. Sjoberg) produced the proposals published by ASCE in 1951 as separate 66,[4] which are the basis for most of the present seismic codes.

In 1951 the Structural Advisory Board for Title 21, the State School Code, was established. This board of structural engineers advised the enforcement agency, now the Office of Architecture and Construction School House Section, on proposed changes and interpretations. They also acted as an appeals board in individual cases.

THE "BLUE BOOK"

The SEAOC Seismology Committee was activated in 1952 and acted jointly with ASCE at the outset. Beginning in 1957 the SEAOC Seismology Committee and Study Groups of the State Association were actively engaged in "preparing appropriate, uniform, seismic code provisions for inclusion in a building code applicable to earthquake-resistant design". The culmination of these efforts was the first edition of "Recommended Lateral Force Requirements" published in 1959 and the first edition with "Commentary" published in 1960.[5] Since that time the Recommended Lateral Force Requirements and Commentary (The Blue Book) has been revised and updated as follows:

First Edition Revised	1963
Second Edition without Commentary	1966
Second Edition with Commentary	1967
Second Edition with Commentary & Addendum	1968
Appendix F - 1969, 1970 & 1971 Revision	1971
Third Edition with Commentary	1973

The continuing study and revision to the "Blue Book" is the responsibility of the Seismology Committees of the four local Associations and the State Association.

On May 9, 1970 the SEAOC Board of Directors appointed the Ad Hoc Committee on Direction Study-Seismic to review the Blue Book. This committee delivered its report to the SEAOC Board of Directors in October, 1971.[6] Some comments from that report are worth repeating.

> "The Committee feels strongly that the Recommendations and Commentary must be revised - as anticipated and stated in 1959 - to account for the new knowledge obtained both from research and the experience of several past earthquakes and in view of the increases of allowable material stresses. Many building users and regulation specifiers are writing their own codes without reference to the extensive design experience of competent structural Engineers."

"The goal and criteria in determining the writing of the code must be corrected to something that can be delivered by both the code, the engineer and the building official. The structural engineer must not inadvertently mislead the public into thinking it has more protection than can be furnished."

"There are two major areas of the design process, moreover, in which the structural engineer has little or no control and which may affect the performance of the structure to a greater degree than any protective measure which the engineer may take."

"The first of these areas concern the siting of the project."

"The second area where the structural engineer frequently has little or no control is the basic architectural layout or concept."

"The Committee recommends that a Special Advisory Board be set up in the Code to establish the design criteria for all important structures, that are dynamically unsymmetrical, or structures on difficult sites. It would be difficult to write a Code to cover all such factors."

"The Recommended Lateral Force Requirements and the Codes resulting therefrom must be simplified to the fullest extent possible."

"Design budgets are usually rather tight and much time and money is often expended on unnecessary precision - time and money that would be better spent on better design, detailing and inspection."

The 1974 SEAOC "Recommended Lateral Force Requirements" adopted in the 1976 edition of the Uniform Building Code is a reorganization of past requirements with the inclusion of new criteria utilizing the "equivalent static force" concept based on correlation of actual seismic and design data. It should be noted that strong motion records of approximately 60 buildings around the Los Angeles Basin during the San Fernando earthquake provided data such that actual earthquake forces could be reconciled to code designs.

CONTINUING EFFORTS

Seismic code development is a continuing project as is evidenced by this "seismic Institute." The AIA Research Corporation acting as the research arm for AIA has a counterpart in the Applied Technology Council which is the research arm of the Structural Engineers Association of California. ATC was established in 1971. The first project was participation in the workshop on Building Practices for Disaster Mitigation.[7]

The second project, under contract to the National Bureau of Standards,[8] together with data gathered and disseminated in the NOAA reports on the San Fernando earthquake[9] provides further data on building periods, forces, ductility, and damping to utilize in further seismic code development. This information is being used in the development of ATC-3 "Tentative Provisions for the Development of Seismic Regulations for Buildings." Other projects on wood frame and masonry construction for residential use are underway.

The cooperation between the architectural and engineering professions on seismic code development continues as evidenced by the participation of architects in the development of ATC-3 and the existence of the CCAIA-SEAOC Joint Commission on Hazardous Buildings. These joint efforts of professional organizations are the best method for developing viable regulations which provide adequate and reasonable protection to the users of buildings designed and constructed thereunder.

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SEISMIC REGISTRATION FOR ARCHITECTS

Stanley Crawley

CONTENTS

SEISMIC REGISTRATION FOR ARCHITECTS

INTRODUCTION

Technically speaking, there is no such thing as seismic registration for architects. However we are as close to that as is humanly possible. The history of state board examinations for architects is fairly well known but the battle between the states (acknowledging reciprocity) has been shrouded in mystery and quite often, vague in regulation. The emergence of NCARB and eventual acceptance of the NCARB examination by all states has helped a great deal in this regard.

REGISTRATION RECIPROCITY

There is little disagreement with the condition that the architect should accept some responsibility for the building being reasonably safe from the hazards of earthquake. The degree of involvement appeared to be a local condition, up until most recently. The state most concerned in this matter had been, and is, California. In fact, California included seismic design problems in their examination as far back as 1937. (How many states did not even have architectural registration laws at that time?) Other western states included some seismic problems on their examination at various times after the initiative set by California. However, California would never accept the degree of rigor of the other examinations and required applicants from other states to either pass their examination or submit a written treatise on seismic design. Other western states followed California's procedure, with the expected reaction of "we won't grant reciprocity unless you do". There was some exception to this standard and some agreements were arranged, but they all seemed to be based on an acceptable treatise.

The treatise theme presented its own problems. First of all, available literature on seismic standards of design was in sparse supply, and in particular little was available in a language usable to an architect. Secondly, there was no safeguard to assure that the submitted treatise was the original work of the applicant. A particularly good treatise might appear over and over again with very little variation, and each time submitted by a new applicant.

Finally, in December 1965, the NCARB Structural Examination included enough seismic questions and problems to be acceptable by all the western states. Consequently all architects registered by NCARB examinations since December 1965, did not have to submit a treatise in order to receive reciprocity from the western states. This continues to be the case and is valid with or without the architect taking the "qualifying" exam. There still remains a large number of architects registered before 1965 that continually apply for reciprocity and need to submit a treatise. With the increased mo-

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bility of our profession and the greater demand by many corporate clients that their architects be in a position to be quickly registered in western states, it was felt by many that the lengthy treatise should be replaced. Clearly, another less time consuming method of assuring the public that the architect was aware of this natural phenomenon was in the best interest of all parties.

SEISMIC SEMINARS

In 1972, at the Western Mountain Region meeting of the American Institute of Architects at Estes Park, the Colorado Society conducted the first seismic seminar. This seminar was quite successful and was acceptable by some states to replace the traditional treatise. Subsequently, the Utah Society and the Graduate School of Architecture at the University of Utah have collaborated in developing and offering to the architectural profession a semi-annual seminar on lateral forces that has since become accepted by all Member Boards of the Western Conference and, in 1975, by the NCARB as an alternative to the treatise.

The Member Boards accepting this seminar numbered fourteen as follows: Hawaii, Alaska, Washington, Oregon, California, Arizona, Utah, Idaho, New Mexico, Colorado, Nevada, Montana, Wyoming, and Guam. Recently two member boards have given up on the treatise altogether and will accept only an approved seismic seminar. Currently, the only approved seismic seminar is the one offered by the architectural school at the University of Utah. It should be noted that this seminar has been given in Oregon, Texas, Colorado and New Jersey as well as in Utah. The next one is scheduled for Seattle, Washington in September 1977. The seminar is open to all architects, and to any individual who is interested in updating their knowledge on the subject. It is not uncommon for recent graduates to take the seminar prior to taking the NCARB examination.

The two day seminar is conducted in a very concentrated manner and with a high level of intensity in both presentation by the staff and problem solving by the individual participant. Suggestions have been made that the length of the seminar be extended but after considerable discussion among the staff members it was decided that this would dilute the impact of the program material on the participant.

The seminar is a sequence of various media which presents the material to the participants in the most succinct and direct manner. The introduction uses two films that dramatically present the theory of plate tectonics, results of earthquakes upon the built environment, and research that is presently being undertaken by different agencies around the world. After the general concept of lateral forces and their affects upon buildings has been explained with the help of mathematical examples, the participants are given work exercises. The problems cover different aspects of lateral forces and require mathematical computations along with descriptive answers.

There is no question but that the emphasis of these seminars is on the structural problems related to earthquake design and application of the minimum standard as outlined in the Uniform Building Code. Also there are some architectural educators that would argue that these structural studies should not be in the architectural curricula but should be left to the engineering consultants. This apparent dichotomy needs further discussion.

The structural emphasis, including numerical calculations, was placed in the seminar at the request of the state boards. They insisted the seminar be rigorous and include a long written examination. They were particularly interested in the examination and its administration. These are the same state board of examiners who are going to pass judgment on the new graduates of the architectural schools. These state boards are keenly aware of the public's image of the architect and the states legislative bodies' idea of technical responsibility of the architect. There are many who think that the technical aspect of architectural registration will become increasingly more demanding particularly with the coming event of recertification.

Perhaps it is appropriate at this time to leave the topic of seismic seminar and review the events facing the young graduate architect. Everyone may not necessarily <u>agree</u> with the current requirements for registration, but surely one <u>must</u> be aware of the requirements.

<u>CURRENT STATE LICENSING REQUIREMENTS</u>

There are three possible examinations the new graduates must face before finally being granted registration. The first is the NCARB qualifying Exam. This is quite similar to the old regular licensing examination. Approximately one half day is spent on structural examination. Numerical work as well as descriptive type questions are involved. Currently 7% to 10% of the questions are earthquake related. Most states do not require the candidate to take the Qualifying Exam if he or she is a graduate from an accredited architectural program. Exceptions to this are New York, New Jersey, Delaware, Illinois, Missouri, Nebraska, and Kentucky. (They require all three examinations.)

The next NCARB Examination is the two-part Design and Site Planning, lasting for a day. Included in the Design solution are required structural framing plans accompanied with explanations of "how" and "why" and means of achieving lateral resistance for improved earthquake designs.

Last comes the professional exam required by all states. It lasts for two days. Currently 7% to 10% of the Design Technology portion of the professional exam is on seismic design. Numerical work is included as well as descriptive type questions. The exam is based upon a single building and one aspect of it deals with the earthquake problem and there may be seven or eight questions related to earthquake design.

Of course, it is theoretically possible for a person to get a passing grade without ever answering one question pertaining to earthquakes. However each year the results are carefully reviewed and so far no one has passed that has not answered correctly a significant number of seismic questions.

NCARB feels that it is only a matter of time before states will require a license renewal or maintenance procedure and is currently preparing a series of monographs on energy conservation, environmental protection, solar energy and earthquake design. Their plan is to make these available to the individual states when they decide to require them for recertification.

It was within this atmosphere that the seismic seminar's outline, sequential work problems and final examination was prepared, and it may be useful now to briefly review the work covered in the two and one half days seminar.

Seismic Seminar Objectives:

1. To obtain a certificate of successfully passing the examination and hence qualifying for reciprocity.

2. Understanding basic earthquake phenomena and information resources.

3. Review the elements of design most useful in earthquake design. A qualitative survey is made of the structural elements available and how they are used in design to provide increased resistance to earthquakes.

4. Numerical calculations of parts of buildings and whole buildings to demonstrate the understanding of lateral force development in various types of buildings.

Typical Outline of Seminar:

<u>Day 1</u>

Earthquake phenomena, causes and history of earthquakes, theory of plate tectonics (slide presentation).
Elastic rebound theory, wave generation, measuring of earthquakes (hand-out notes).
Examples of earthquake induced failures (slide presentation).
Seismic Movement.
Structural Dynamics (one degree of freedom).
Film: "The Not So Solid Earth".

<u>Day 2</u>

Introduction to Equivalent Static Load Process.
Response of an infinitely rigid building to a seismic factor.

Overturning of buildings and elements.
Parts of buildings.
Problem #1 Working Session.
Structural elements, horizontal and vertical.
Illustrative example of small symmetrical building.
Problem #2 Working Session.
Horizontal and Vertical elements, details, use in buildings.
Relative Stiffnesses.
Torsion in buildings, example problem.
Problem #3 Working Session.
Distribution of forces in high-rise buildings.
Illustrative problem.
Film: "The City That Waits to Die."
Work Session on Problem #4.

Day 3

Review all Work Problems.
Frame Analysis - approx. and computers.
Dynamic Analysis.
Philosophy of Design and State of the Arts, Costs.
Balance Risk Concept.
Review of Seminar.
Examination.

Modifications that have been made to the program since its inception include the dispensing of additional material prior to the commencement of the program, alerting the participant to the fact that he must fully understand the operation of his calculator prior to beginning the seminar, and informing him of the intensity of the work during the two days. An example of advance information mailed to each participant is the paper "Introduction to Earthquake Resistant Building Systems" available at this workshop. In an effort to maintain the relevancy of the material that is presented, all new developments and any modifications that have been made to the Uniform Building Code are included. Furthermore, as new research data in seismic design becomes known and begins to exert its influence on building codes, it will be added to the program.

As was noted earlier, there has been some feeling in the past that the treatise was not always the work of the individual but a form of collaboration.

STATE OF THE ARTS

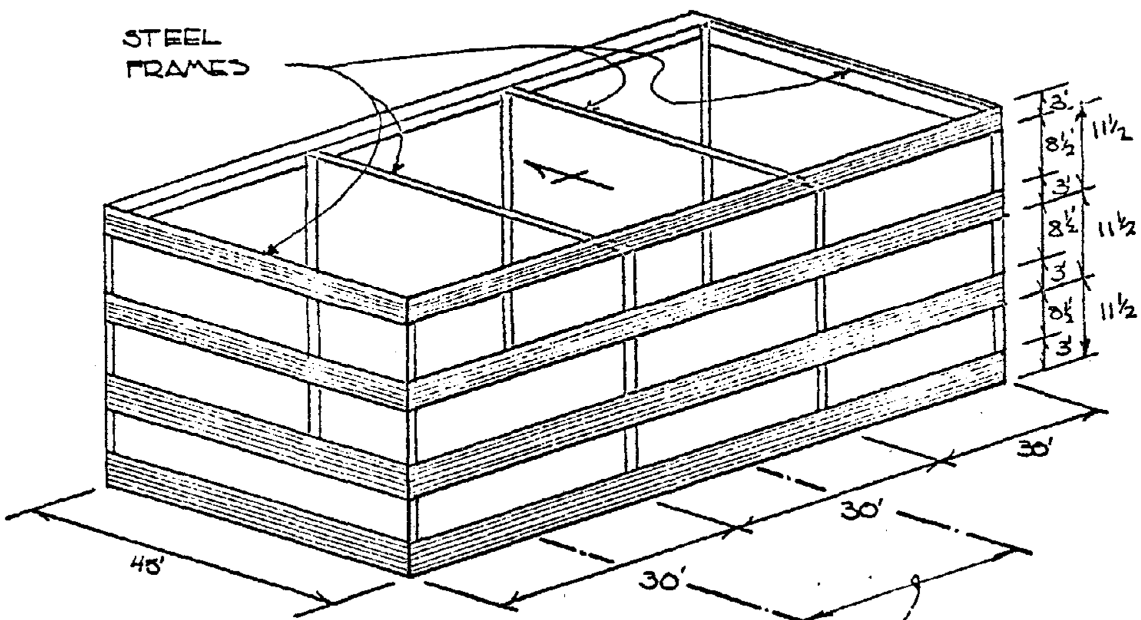
There appears to be an emerging awareness of the state governments to earthquake hazards and the responsibility of the state for the safety of their citizens. New state legislation is under consideration for reducing these hazards. Included are more restrictive measures for building types, location and construction standards. All of the western states use part or all of the 1976 Uniform Building Code. It is felt by many to be the best code for earthquake design. It is updated about every three years. If <u>every</u> building conformed to the 1976 UBC, there would be a considerable risk reduction.

Some buildings in certain locations should be investigated in greater depth than required by the UBC. This situation presents little difficulty, since many consulting engineering firms have access to a variety of computer programs to handle the structural aspect of earthquake design. The cost of such service is moderate. Once the architect is aware of the dangers involved and the alternatives open to him, a good safe design is within easy reach.

The following example illustrates early seismic calculations, extends these calculations for more definitive use by the engineer and finally shows a simple dynamic analysis and its practical application.

EXAMPLE EXERCISE

The building shown in the figure below is symmetrical for both the N-S axis and the E-W axis. There are four continuous three-story steel frames located as shown in the figure. The frames do not have interior columns. All columns are the same size, all floor beams are the same size, and all roof beams are the same size. Standard moment resisting connections are used throughout. Floor and roof construction consists of R/C joists and slab (18" + 2-1/2") which weigh 94 lbs per square foot. The joists span the 30 feet between frames.
The building is in Zone 4.
The design snow load is 30 psf.
Occupancy is for large groups (over 300) in open spaces on each floor.
30% of a 100 psf floor live load should be included in the analysis.
A geotechnical analysis produces a characteristic site period of T_S = 2 seconds.



To simplify the work effort consider earthquake design in the N-S direction only and focus attention on a typical interior frame.

Other dead loads are as follows:

Ceiling construction	10 psf
Roofing	6 "
Windows and frames	10 "
Spandral beams and mosonry	60 "

Assume that the girders weigh 150 lbs/foot.

SOLUTION

Roof Loads

Roofing	6 psf	
Joists & Deck	94	
Ceiling	10	
	110 (30)(45) =	148,500#
	Girder (150)(45) =	6,750
	Spandrel (2)(3)(30)(60) =	10,800
	Windows (4¼)(2)(30)(10) =	2,550
		168,600

Say 169 kips

Floor Loads

Joists & Deck	94	
Ceiling	10	
Live Load	30	
	134 (30)(45) =	180,900
	Girder (150)(45) =	6,750
	Spandrel (2)(3)(30)(60) =	10,800
	Windows (8½)(2)(30)(10) =	5,100
		203,550

Say 204 kips

Total W = 169 + 2(204) = 577 kips

$Z = 1.0$ (Zone 4)

$I = 1.25$ (Over 300 persons in one room)

$K = 1.0$ (Standard Moment Resisting Joists)

$T = (0.1)(3) = 0.3$ seconds

$$C = \frac{1}{15\sqrt{0.3}} = 0.12$$

$$\frac{T}{T_S} = \frac{0.3}{2} = 0.15 < 1.0$$

$S = 1.0 + 0.15 - 0.5(0.15)^2 = 1.14$

$CS = 0.12(1.14) = 0.137 < 0.14$

TOTAL BASE SHEAR $V = (1)(1.25)(1.0)(0.12)(1.14)(577) = 98.7$

Say 100 kips

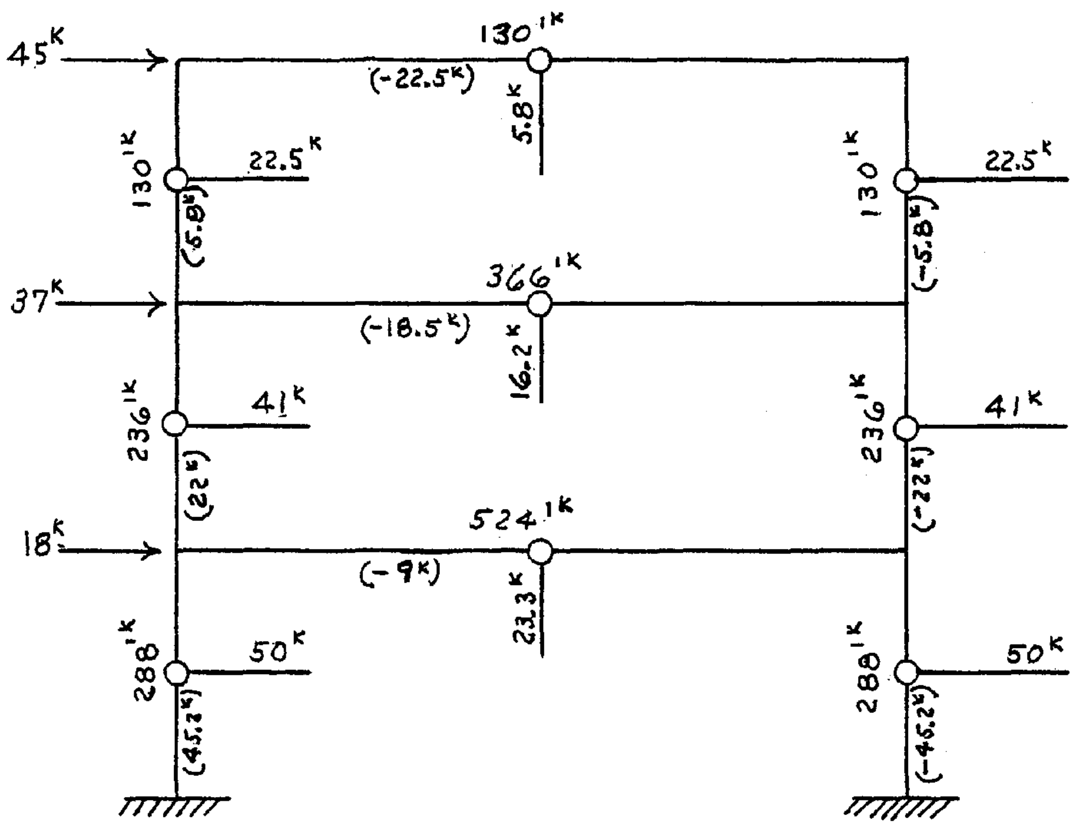
$T = 0.3 < 0.7 \quad \therefore F_t = 0 \qquad (V - F_t) = 100$ kips

Floor	N	W_x	h_x	$W_x h_x$	$\frac{W_x h_x}{\sum W_i h_i}$	F_x	$F_x h_x$
Roof	3	169	34.5	5831	0.45	45	1553
3rd	2	204	23.0	4692	0.37	37	851
2nd	1	204	11.5	2346	0.18	18	207

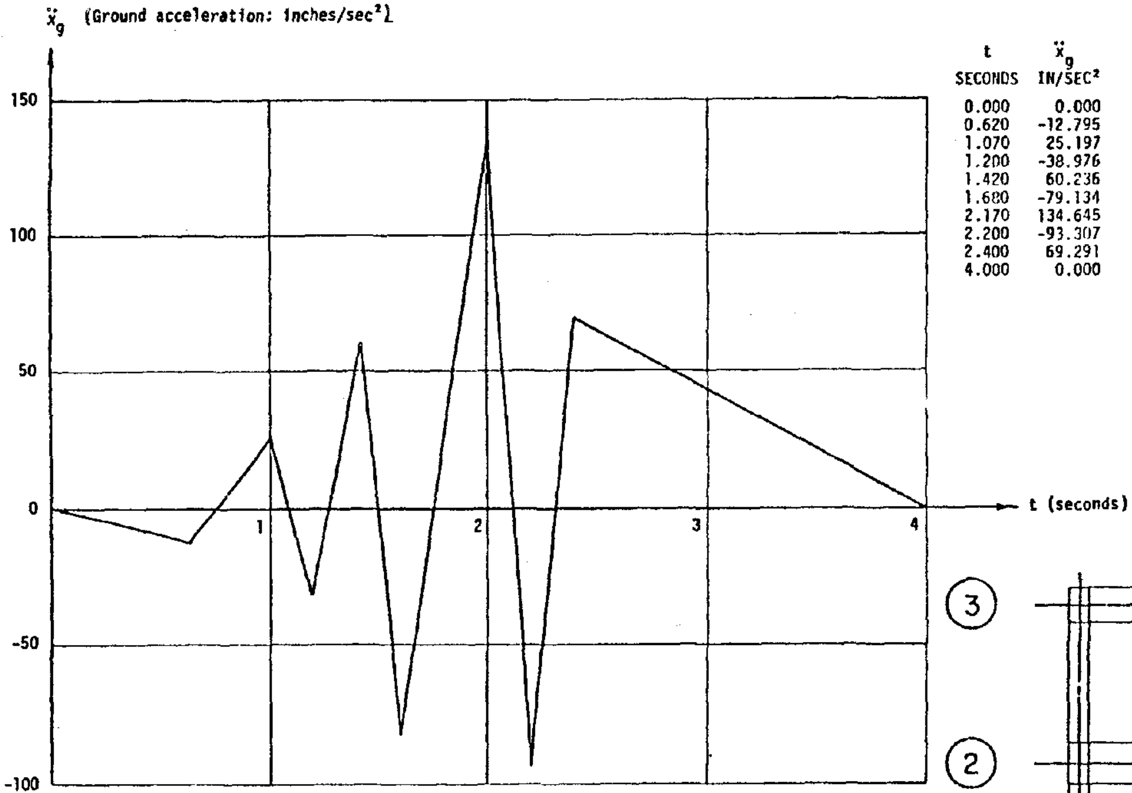
$\sum$ 12,869 1.0 100 2611 ft-kips

Stabilizing Moment $577\left(\frac{45}{2}\right) = 12,983$ ft-kips

<u>Approximate Solution by Portal Method</u>

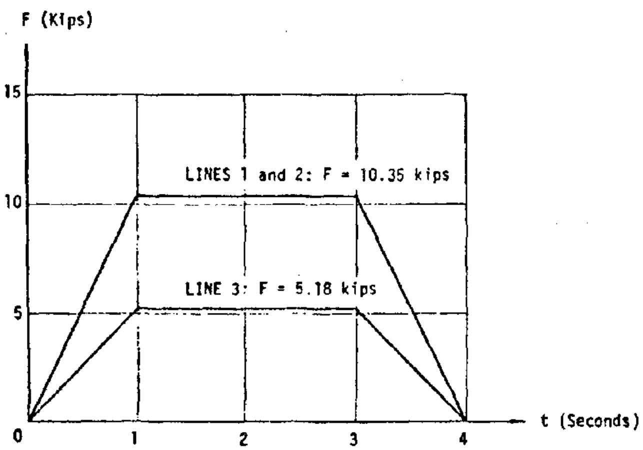


Drift - Unknown



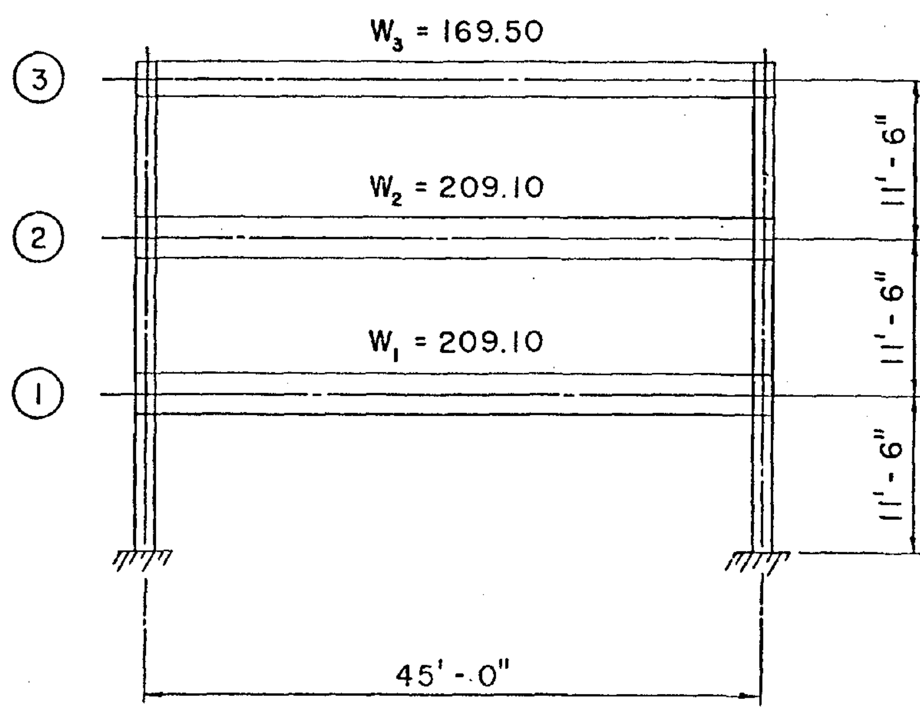
t SECONDS	$\ddot{x}_g$ IN/SEC²
0.000	0.000
0.620	-12.795
1.070	25.197
1.200	-38.976
1.420	60.236
1.680	-79.134
2.170	134.645
2.200	-93.307
2.400	69.291
4.000	0.000

SIMULATED EARTHQUAKE



SIMULATED WIND

Roof Girder *W 30 x 116*
Floor Girder *W 36 x 170*
Columns *W 14 x 202*

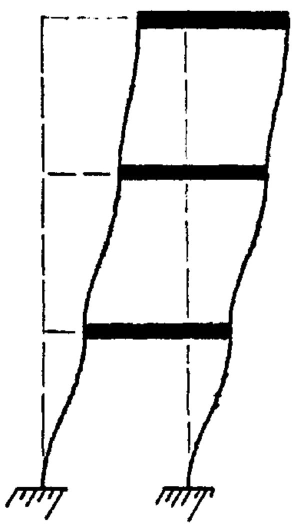


5 PERCENT MODAL DAMPING

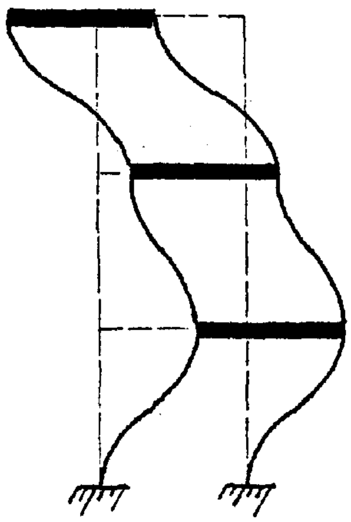
SIMULATED WIND FORCING FUNCTION

MODE	EIGENVALUE	ANGULAR FREQUENCY (RAD/SEC)	NATURAL FREQUENCY (CYC/SEC)	PERIOD (SECS)
1	.40697	16.54571	2.63333	.380
2	3.09678	45.64132	7.26404	.138
3	6.15756	64.35867	10.24300	.098

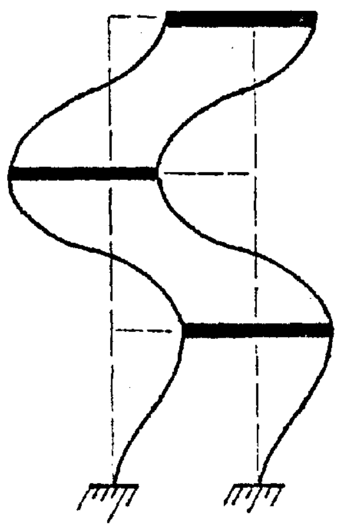
	MODE SHAPES		
	1	2	3
1st Floor	0.462	1.000	0.749
2nd Floor	0.821	0.322	-1.000
Roof	1.000	-0.896	0.587



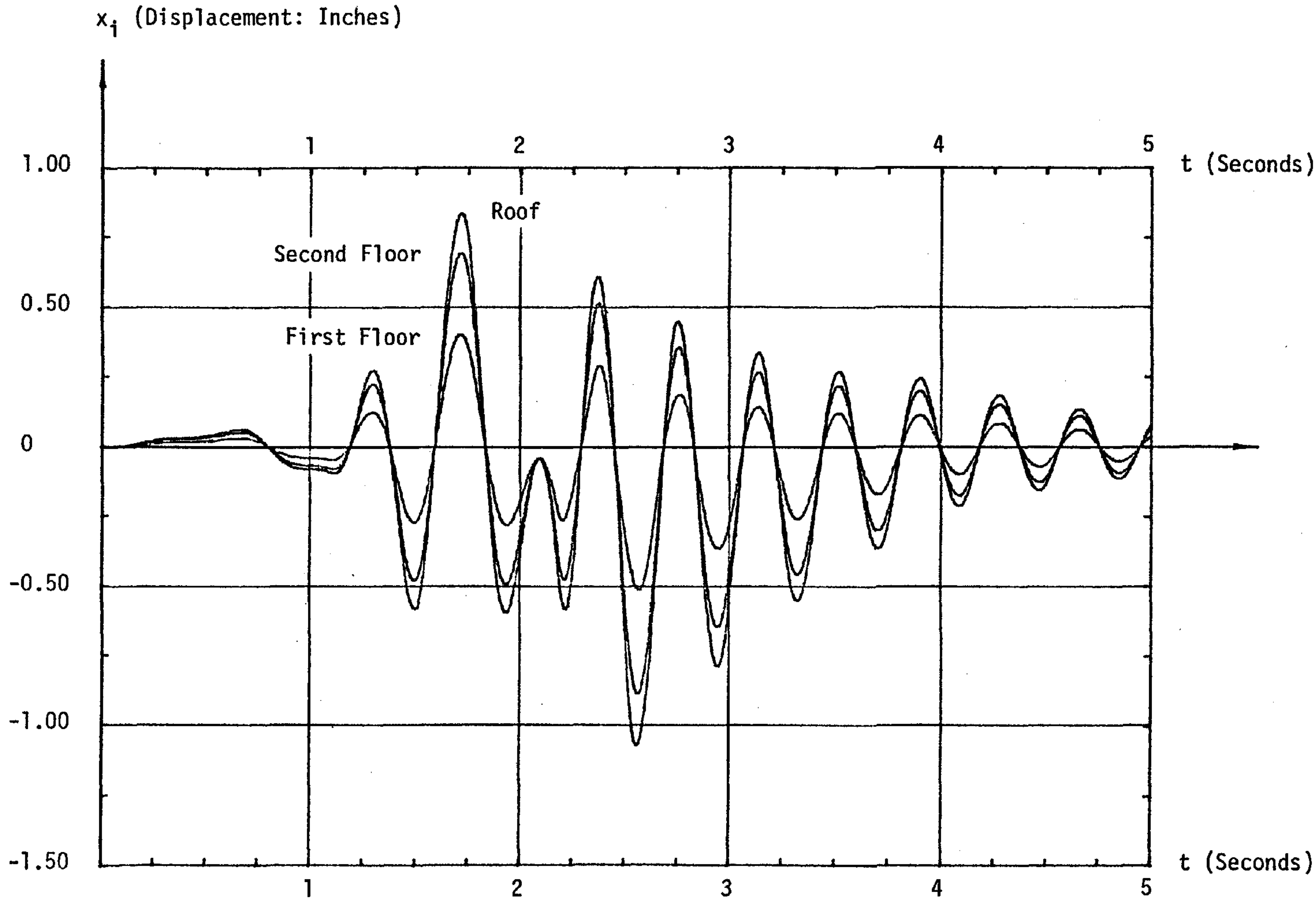
τ_1 = 0.380



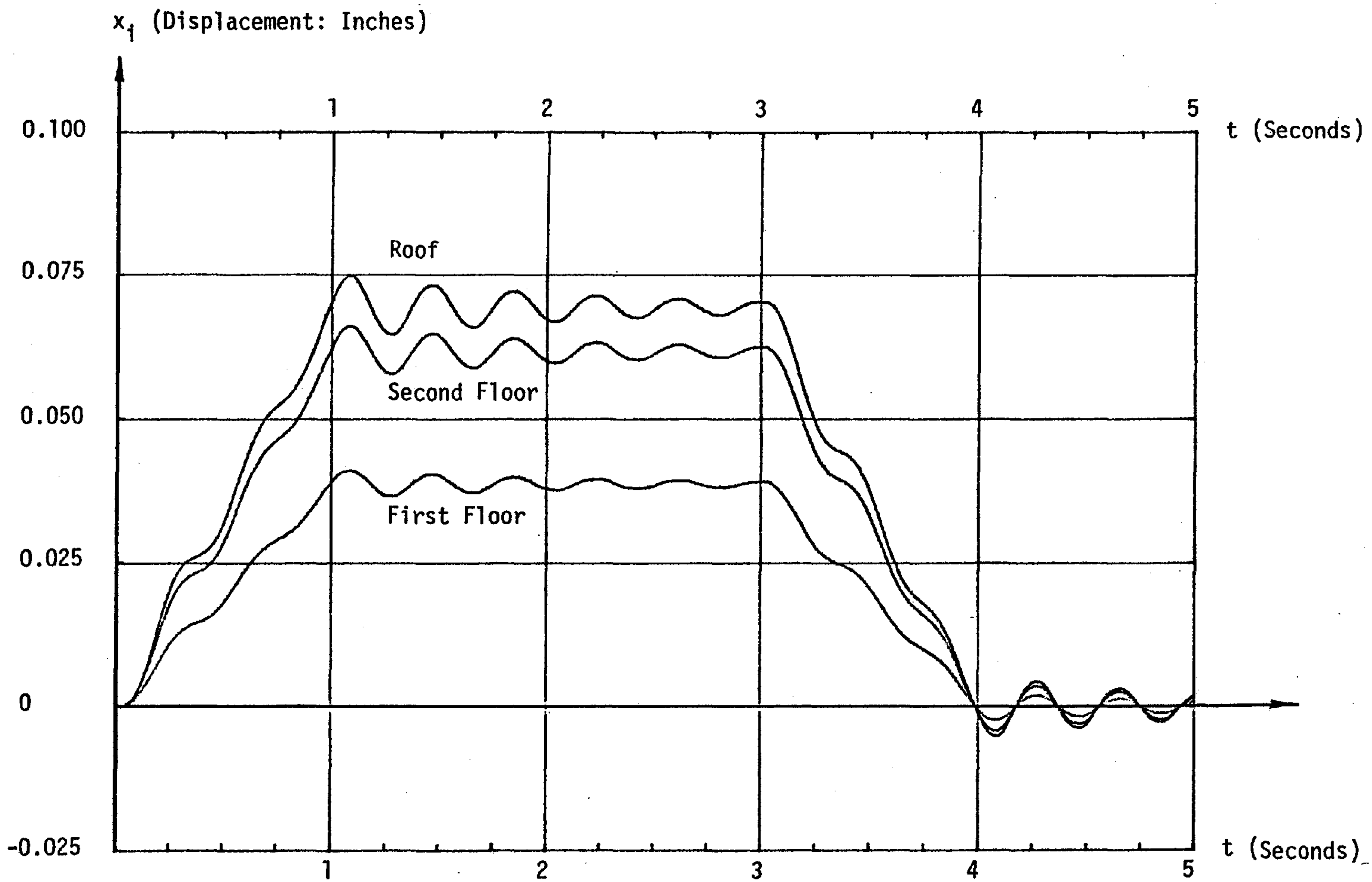
τ_2 = 0.138



τ_3 = 0.098



Simulated Earthquake Forcing Function



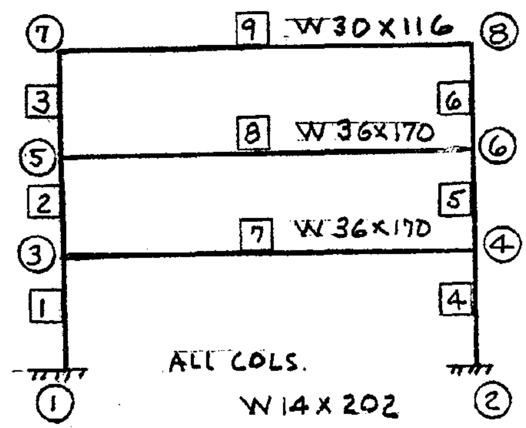
Simulated Wind Forcing Function

STEEL BUILDINGS: ANALYSIS AND DESIGN
CRAWLEY & DILLON

PLANE FRAME ANALYSIS BY DISPLACEMENT METHOD
W O CARTER

* * * * * * * * * * *
* J O I N T D A T A *
* * * * * * * * * * *

JOINT	COORDINATES X (FEET)	COORDINATES Y (FEET)	RESTRAINT CONDITION X	Y	R
1	.000	.000	R	R	R
2	45.000	.000	R	R	R
3	.000	11.500			
4	45.000	11.500			
5	.000	23.000			
6	45.000	23.000			
7	.000	34.500			
8	45.000	34.500			



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* M E M B E R D A T A *
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MEMBER	END JOINTS A	END JOINTS B	LENGTH (FEET)	CROSS-SECTION PROPERTIES AREA (INS**2)	I(ZZ) (INS**4)	MODULUS OF ELASTICITY (KSI/1000)
1	1	3	11.500	59.400	2540.00	29.000
2	3	5	11.500	59.400	2540.00	29.000
3	5	7	11.500	59.400	2540.00	29.000
4	2	4	11.500	59.400	2540.00	29.000
5	4	6	11.500	59.400	2540.00	29.000
6	6	8	11.500	59.400	2540.00	29.000
7	3	4	45.000	50.000	10500.00	29.000
8	5	6	45.000	50.000	10500.00	29.000
9	7	8	45.000	34.200	4930.00	29.000

TOTAL WEIGHT OF FRAME: 17.248 TONS

LOADING PATTERN 1 OF 2 LOADING PATTERNS

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* J O I N T L O A D I N G *
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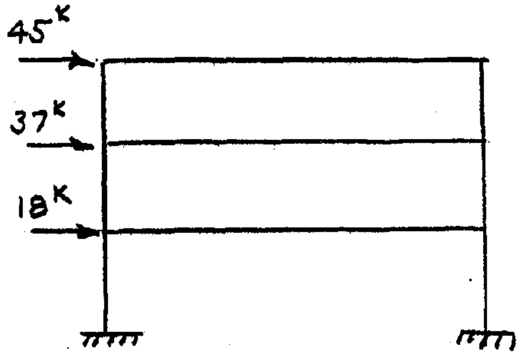
JOINT	LOADING F(X) (KIPS)	F(Y) (KIPS)	COUPLE (KIP-FEET)
3	18.000	.000	.000
5	37.000	.000	.000
7	45.000	.000	.000



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* M E M B E R L O A D I N G *
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NO MEMBERS WITH CONCENTRATED LOADS IN PATTERN

NO MEMBERS WITH DISTRIBUTED LOADS IN PATTERN

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* MEMBER WEIGHTS ARE INCLUDED IN ANALYSIS *
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* J O I N T D E F L E C T I O N S *
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JOINT	DEFLECTIONS D(X) (INCHES)	D(Y) (INCHES)	ROTATION (RADS)
1	.0000	.0000	.00000
2	.0000	.0000	.00000
3	.2590	.0021	-.00165
4	.2561	-.0047	-.00151
5	.5827	.0031	-.00137
6	.5759	-.0073	-.00126
7	.8183	.0033	-.00117
8	.8047	-.0081	-.00098

LOADING PATTERN 1 OF 2 LOADING PATTERNS

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* M E M B E R E N D A C T I O N S *
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MEMBER	T(A) (KIPS)	V(A) (KIPS)	M(A) (K-FT)	T(B) (KIPS)	V(B) (KIPS)	M(B) (K-FT)
1	-24.865	48.922	354.516	27.190	-48.922	208.084
2	-11.398	38.822	211.028	13.722	-38.822	235.420
3	-1.280	20.144	107.051	3.604	-20.144	124.600
4	59.361	51.078	360.885	-57.037	-51.078	226.511
5	33.588	43.178	237.284	-31.264	-43.178	259.265
6	11.165	24.856	130.437	-8.841	-24.856	155.410
7	7.900	-15.792	-419.112	-7.900	23.448	-463.795
8	18.322	-12.442	-342.471	-18.322	20.099	-389.702
9	24.856	-3.604	-124.600	-24.856	8.841	-155.410

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* R E A C T I V E F O R C E S *
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JOINT	REACTIONS R(X) (KIPS)	R(Y) (KIPS)	COUPLE (KIP-FEET)
1	-48.922	-24.865	354.516
2	-51.078	59.361	360.885

LOADING PATTERN 2 OF 2 LOADING PATTERNS

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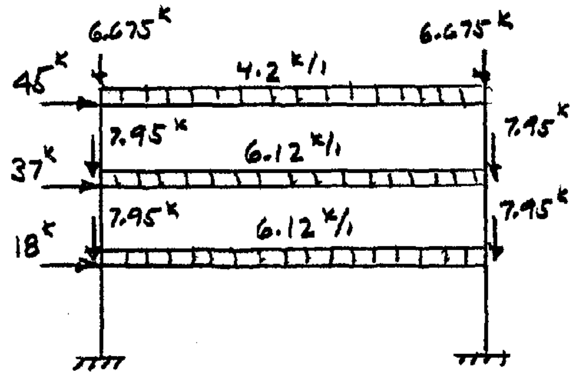

JOINT	LOADING F(X) (KIPS)	F(Y) (KIPS)	COUPLE (KIP-FEET)
3	18.000	-7.950	.000
5	37.000	-7.950	.000
7	45.000	-6.675	.000
4	.000	-7.950	.000
6	.000	-7.950	.000
8	.000	-6.675	.000

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* M E M B E R L O A D I N G *
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NO MEMBERS WITH CONCENTRATED LOADS IN PATTERN

MEMBER	UNIFORMLY DISTRIBUTED LOADING ORIENTATION (AXES)	W(X) (KIPS/FOOT)	W(Y) (KIPS/FOOT)	M(O) (K-FT/FOOT)
7	S	.000	-6.120	.000
8	S	.000	-6.120	.000
9	S	.000	-4.200	.000

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* MEMBER WEIGHTS ARE INCLUDED IN ANALYSIS *
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LOADING PATTERN 2 OF 2 LOADING PATTERNS

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* J O I N T D E F L E C T I O N S *
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JOINT	D(X) (INCHES)	D(Y) (INCHES)	ROTATION (RADS)
1	.0000	.0000	.00000
2	.0000	.0000	.00000
3	.2533	-.0294	-.00364
4	.2619	-.0361	.00049
5	.5805	-.0481	-.00284
6	.5780	-.0585	.00021
7	.8430	-.0560	-.00401
8	.7800	-.0674	.00185

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MEMBER	T(A) (KIPS)	V(A) (KIPS)	M(A) (K-FT)	T(B) (KIPS)	V(B) (KIPS)	M(B) (K-FT)
1	367.610	.670	165.828	-365.285	-.670	-158.129
2	235.427	-40.427	-267.966	-233.103	40.427	-196.948
3	99.895	-70.784	-355.044	-97.571	70.784	-458.968
4	451.836	99.330	549.572	-449.512	-99.330	592.724
5	280.413	122.427	716.278	-278.089	-122.427	691.633
6	112.340	115.784	592.532	-110.016	-115.784	738.978
7	-23.097	121.908	426.095	23.097	161.148	-1309.002
8	6.644	125.258	551.992	-6.644	157.799	-1284.166
9	115.784	90.896	458.968	-115.784	103.341	-738.978

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* R E A C T I V E F O R C E S *
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JOINT	R(X) (KIPS)	R(Y) (KIPS)	COUPLE (KIP-FEET)
1	-.670	367.610	165.828
2	-99.330	451.836	549.572

EXISTING BUILDINGS AND SEISMIC SAFETY

Boris Bresler

CONTENTS

EXISTING BUILDINGS AND SEISMIC SAFETY

INTRODUCTION

Recent experience has shown that major earthquakes in urban communities result in loss of human lives and injuries, as well as cause substantial disruption of social services and economic life of the community. These losses and disruptions, directly or indirectly, relate to damage in structures, roadways, sanitary systems, and mechanical or electrical equipment. This lecture deals only with buildings, and specifically two categories of problems are examined.

1. Residual safety of buildings damaged in a major earthquake and remedial measures such as repair or demolition.
2. Potential earthquake hazards in existing buildings and possible remedial measures, such as strengthening or demolition.

The choices available to the building professions (architects and engineers) after the damage has occurred are relatively limited. Essential tasks include prompt and effective post-earthquake assessment of damage and implementation of appropriate remedial measures. Assessment of potential hazards and abatement of these hazards presents an opportunity to minimize damage in future earthquakes. In this case, however, many choices are available, often immobilizing both the building professionals and society at large. Some directions for possible action by design professionals are outlined here.

ASSESSING RESIDUAL SAFETY OF EARTHQUAKE DAMAGED BUILDINGS

When extensive damage occurs following a major earthquake, the local jurisdiction responsible for the health and safety of the community must assess the extent of damage and evaluate the relative safety of continued occupancy of the damaged buildings. Most local agencies who have this responsibility are not adequately staffed to carry out such an assessment under the emergency conditions following a major disaster. Assistance is generally sought from neighboring jurisdictions, state and federal agencies, as well as qualified professionals who may be deputized to carry out the difficult task of evaluating critical hazards and to help with decisions to vacate or demolish potentially dangerous buildings.

The most effective and efficient means of organizing inspections of damaged areas is generally through established agencies of local jurisdictions. However, even with maximal aid from neighboring local and national agencies, rapid and effective procedures for inspection and evaluation of damage under emergency conditions require extensive advance planning. This planning must provide for organizing, mobilizing and coordinating the work of trained inspection teams, and must be periodically tested under conditions simulating an emergency. Finally, implementation of these plans may require special enabling ordinances which would give the authorities jurisdiction to enforce such safety measures as prohibiting entries into buildings deemed hazardous and demolishing buildings posing a serious threat to the community.

To assist local and national agencies in formulating such plans, Applied Technology Council has included in its "Recommended Comprehensive Seismic Design Provisions for Buildings" which is scheduled for publication in 1977 and herein referred to as ATC-3 Report, a section dealing with emergency post-earthquake evaluation of damaged buildings. A summary of this section has been published in the Proceedings of the Sixth World Conference on Earthquake Engineering.[1]

The main elements of the post-earthquake emergency evaluation of damaged buildings include:

Advance planning: utilizing governmental and private disaster relief agencies; importance of participation of professional associations.

Organizing, training, mobilizing, and equipping personnel.

Evaluation process: priorities for evaluation, deployment of teams to damage areas, special attention to hospitals, utilities, communication centers, schools, nursing homes, detention centers, office and multiple unit residential buildings, manufacturing plants, commercial buildings.

Field evaluation: Identification of lateral force-resisting system, qualitative hazard criteria, structural and nonstructural damage, systematic recording of observations.

Hazard abatement alternatives: immediate demolition (total or partial), repair prior to occupancy, repair with concurrent occupancy, or qualitative or analytical re-evaluation (delayed decision regarding demolition or repair).

REPAIR OF DAMAGED BUILDINGS

Following the emergency period, a further evaluation of damaged buildings is required to determine appropriate remedial measures, such as repair or demolition. Some of the details of damage assessment and repair techniques are dealt with in the ATC-3 Report mentioned above. The decision as to whether the damage should be repaired or the building demolished will be based partly on technical considerations, such as the level of structural safety which can be restored through repair, and partly on economic considerations, such as the cost and benefit of repair vs. the cost and benefit of demolition and new construction. The desired level of strength in a repaired building generally is at least equal to or greater than the prior strength of the building, assuming that the repaired building is expected to withstand another earthquake similar in intensity to that which caused the current damage.

When damage in concrete structures is minor, consisting of residual cracks not greater than 0.2 inches wide, the repair usually consists of crack filling, restoring the continuity and strength of original material. In steel structures, minor damage may be repaired by straightening or welding. Some local damage may be repaired by replacing damaged sections by equivalent or stronger segments. This is not always satisfactory because an increase in strength (or stiffness) in the zone where the damage occurred may alter the behavior of the structure and cause greater damage elsewhere in a subsequent earthquake. Another kind of repair requires modifications in the structural system. In this case, it is possible to improve the subsequent performance of the structure by adding new elements.

ASSESSING POTENTIAL EARTHQUAKE HAZARDS IN EXISTING BUILDINGS

A large number of buildings located in regions of high seismic activity do not meet current seismic requirements. These include many old buildings designed prior to the introduction of adequate earthquake regulations and using types of construction which subsequently proved vulnerable to earthquake damage. Other old buildings may be vulnerable to damage because they deteriorated due to a variety of conditions, such as previous earthquake damage, fire damage, foundation settlement, or alterations. Most of these buildings are older low-rise buildings, including apartment buildings, commercial, industrial or public buildings constructed without adequate provision for ductile response or without adequate horizontal bracing or membrane system tying together the vertical elements of the buildings.

In a recent study (2), it has been estimated that 350 fatalities and 3500 to 5200 injuries may occur in a nearly 200 block area in San Francisco where severe damage may happen in the event of a 1906-type earthquake. The number of potentially hazardous buildings approaches 1400 residential buildings, containing 35,000 living units, and 2800 non-residential buildings. These estimates are based on sampling techniques which provide a framework for overall planning. More precise evaluation of the level of hazard requires a systematic procedure for evaluating potential hazards in individual typical buildings.

A tentative recommended procedure for such evaluations was developed by the ATC Task Group on Existing Buildings and was included in the ATC-3 Report. Other procedures have been proposed by several groups in U.S.A. and abroad.(3)

During preparation of the ATC recommended procedures, it became apparent that the data base for establishing an acceptable level of hazard was not adequate. Also, using compliance with design code provisions as a criterion for assessing hazards in existing buildings was deemed inappropriate. Therefore, the ATC recommendations provide for evaluation of selected categories of buildings based on adequacy of seismic design criteria at the time of construction, type and density of occupancy, use of the building, type of building construction, and on regional severity of ground motion. Special hazards such as irregularities in plan configuration or in vertical configuration of elements resisting seismic effects, are also accounted for in establishing priorities for evaluation.

Original design criteria: As knowledge of building response to earthquakes accumulated with field observations of performance, seismic design criteria in different codes reflected this experience. Therefore, buildings conforming to code requirements at the time of design may no longer conform to the current code for seismic design criteria. For different types of buildings, the degree of noncompliance is different for different codes. Therefore, types of buildings built at different times represent different levels of hazard.

Occupancy potential: A measure of the number of persons that might be in a building at the time of an earthquake is defined as OP (occupancy potential):

$$OP = \sum \frac{A_f}{SFPO}$$

Where:

OP - occupancy potential

A_f - floor area of given occupancy

SFPO - square feet per occupant for each area, A_f, as specified.

For example, a 20 unit apartment building of 22,000 square feet, based on specified SFPO of 200 for this type of occupancy, will have a PO of (22,000/200) = 110.

Building usage: High priority for evaluating seismic hazards is assigned to essential facilities, such as hospitals and essential community service facilities. Next in order of priorities are high density occupancy buildings where movement of occupants may be restricted - theaters, schools, hotels, apartments, nursing homes, correctional institutions, and other buildings where occupancy potential exceeds specified limits.

Severity of ground motion: Seismic zoning maps are used to divide United States into regions of varying seismic intensity. Both effective peak accelerations and effective peak velocities of ground motion are used for zoning.

Special hazards: Four principal sources of special seismic hazards may be identified:

(1) buildings having highly irregular plan configuration (asymmetry, reentrant corners, etc.) -- resulting in large torsional effects;

(2) severe discontinuities in stiffness (or strength) along the height of the building;

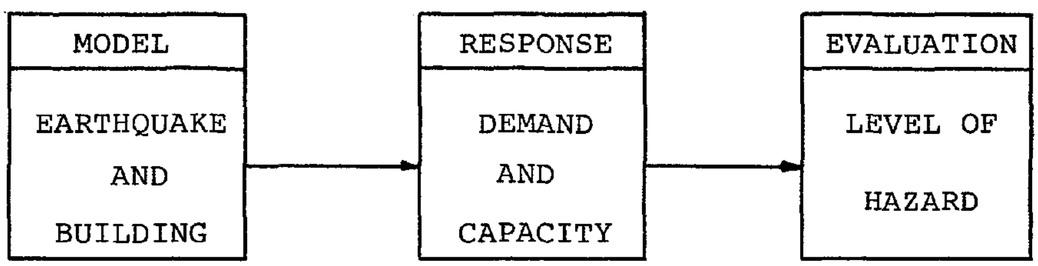
(3) exterior non-structural elements such as walls and parapets that might collapse during an earthquake posing a hazard to life safety; and

(4) interior non-structural elements that might collapse or malfunction during an earthquake, posing a hazard to life safety.

METHODS FOR EVALUATING EARTHQUAKE HAZARDS

The basic process of evaluating earthquake hazards reflects a relationship between response demand and response capacity, given the estimates (models) of earthquake loading and of structural and non-structural characteristics of a building.

This process is illustrated in the diagram below, where the response is calculated on the basis of appropriate models of earthquake and building characteristics. Comparing response demand with response capacity provides and assessment of level of hazard.



Hazard evaluation may be formal (quantitative) or informal (qualitative), simple or complex, implicitly or explicitly probabilistic.

For some buildings a qualitative evaluation may be sufficient. This shall consist of an on-site inspection, and, wherever possible, an examination of all available pertinent documentation on design, construction and inspection. Where such documentation is not available or incomplete, field measurements must be made to establish the dimensions and, in-so-far as possible, the construction details.

The report of qualitative evaluation shall include sketches showing the dimensions of the primary structural systems which resist earthquake forces. The sketches shall also include cross-sectional details for some critical members, typical joint details, and any other details considered to be crucial for the structural system to perform satisfactorily during earthquakes. If a structural system or non-structural element is classified as inadequate, one or more specific reasons for this classification shall be provided in the report.

Qualitative evaluation shall classify each primary structural system and each non-structural element as either: (a) adequate, (b) inadequate, or (c) uncertain adequacy. Buildings classified in the latter two categories must be strengthened, demolished, or undergo an analytical evaluation.

An analytical evaluation, in addition to a site visit and an inspection of original or newly prepared documentation based on field inspection, shall consist of calculating response demand and response capacity using appropriate models of the earthquake loading and building characteristics.

Response demand and response capacity can be expressed in terms of forces (axial, shear, flexural or torsional moments) or in terms of deformations (displacements or rotations). Calculation or response demand and response capacity may be made using varying degrees of approximation.

A relatively simple approach which in some cases may give a measure of earthquake hazard is to calculate an earthquake capacity ratio. This ratio R_c is defined as:

$$R_c = (V_{rc}/V_{rd})$$

Where

V_{rc} - calculated response capacity in terms of force or deformation, and

V_{rd} - calculated response demand in terms of corresponding force or deformation.

If R_c is equal to or greater than unity, then the particular element is "safe". Generally, it may be necessary to calculate R_c for many structural and non-structural elements to establish the critical elements, i.e., those which have a low value (less than unity) of R_c and whose failure will pose significant hazards (risk of life, damage in building, potential fire, unsafe continued occupancy, injury to people in adjacent spaces).

Different methods of relating capacity ratio R_c and hazard in an existing building have been proposed, but no conclusive study or experience is available to select one particular criterion.

MINIMUM ACCEPTABLE LEVELS OF HAZARD

A variety of options are available in hazard abatement:

(1) When hazard abatement is impossible or not economical, the building must be demolished.

(2) When strengthening and continued economic use of the building are feasible, the building must be strengthened to an acceptable level of performance (R_c) within the required time.

(3) Intermediate corrective measures may include changes in use or occupancy, a reduction in the number of stories (partial demolition), or a reduction in projected life-time (legal commitment to demolish within prescribed time limit).

(4) Acceptable combination of (2) and (3) above.

Because data are lacking for objectively correlating R_c values with various risks and for defining acceptable levels of hazard, decisions regarding hazard mitigation must be made on a subjective basis. These subjective decisions must be constrained by reasonable judgement, and eventually verified using probabilistic risk analysis of seismic hazards and cost/benefit analysis.

For example, a subjective decision to accept a low value of R_c (say, 0.10) may be rationalized for the existing inventory of buildings. In realistic terms, this subjective decision is based on accepting the principle that the earthquake safety of existing buildings will be improved through a natural process of "survival of the fittest".

On the other hand, requiring uniform performance (risk of damage) for existing old and new buildings would necessitate upgrading all existing buildings to a value of $R_c = 1.0$, possibly involving considerable cost. Such expenditure may or may not be economically justifiable, except when special conditions require the cost of strengthening a building is not justified, the structure must be demolished or the larger risk of damage accepted.

An intermediate solution may be provided by varying acceptable values of R_c depending on the nature and consequences of damage in different buildings.

The ATC-3 Report contains a recommendation that for buildings housing essential facilities the minimum acceptable value of R_c is 0.5, except that for exterior non-structural elements the minimum acceptable value of $R_c = 1.0$. For other building categories, depending on the value of OP (occupancy potential) the minimum acceptable value of R_c is:

$$0.25\left(1 + \frac{OP-100}{700}\right) \leq R_c \leq 0.5$$

except that for exterior non-structural elements the minimum acceptable value of $R_c = 0.5$.

Other criteria for minimum acceptable levels of hazard have been proposed by various investigators, but they -- just as the ATC-3 recommendations -- require further verification.

PERMISSIBLE TIME FOR REMEDIAL MEASURES

For economic and technical reasons the objectives of hazard abatement in all existing buildings can not be accomplished in a short period of time. For different categories of buildings the permissible time for compliance with hazard abatement requirements may vary from 2 to 20 years.

ATC-3 Report contains a recommendation that time for remedial measures for essential buildings be limited to T_X shall be proportional to the value of R_C and can vary with OP, as follows:

$$T_X = \alpha(1 + \frac{200}{OP})R_C$$

Coefficient α should be selected by the local jurisdiction to accommodate the time limits T_X to local conditions. For example, an apartment building with an $OP = 400$, $R_C = 0.25$, and $\alpha = 16$, must be strengthened within six years.

STRENGTHENING

When the estimated seismic hazards exceed the minimum acceptable level the building has to be either strengthened or demolished. The choice between these two alternatives will be made primarily on the basis of economical considerations, except when social or historical values control the decision.

Strengthening a building for adequate seismic response is a unique problem in design, and each building poses special constraints for design of appropriate strengthening at a reasonable cost. Because of the large variety of the special constraints, description of strengthening measures cannot be treated in a comprehensive manner in a brief survey lecture.

Two basic types of strengthening must be considered: (a) retaining existing structural system and strengthening individual members or connections and (b) modifying existing structural system by adding new elements such as walls, trussess, columns, or girders. If the latter type of strengthening is used, the seismic response of the building may be altered substantially, increasing the response demand. Therefore, it is necessary to ensure that the modified structure has adequate capacity to withstand this increased response demand.

ATC-3 Report contains a section on repair and strengthening of structures which describes some of the basic steps in design of these remedial measures, and contains a bibliography which should be helpful to the designer confronted with these problems.

EVALUATION OF QUALIFIED HISTORICAL BUILDINGS

Historical buildings require special consideration. These buildings, deemed to be of importance to the history, architecture, or culture of an area, and so designated by appropriate governmental agency, should be evaluated on an individual basis. The standards for such evaluation may, in some cases, be more relaxed or in other cases, more stringent than those for similar ordinary buildings.

INTEGRATED HAZARD ASSESSMENT

While the focus in this discussion has been on assessment of seismic hazards, it is highly desirable to develop procedures and criteria for an integrated assessment of natural hazards. These should include such exposures as fires, floods, severe storms and tornadoes, tidal waves, as well as earthquakes, and seiches. Whenever possible, abatement of hazards should be executed simultaneously, which would be much less costly than separate assessments and separate hazard abatement measures. Also individual requirements for abatement of separate hazards may be contradictory, and these contradictions must be resolved before appropriate abatement measures are selected.

SOCIO-ECONOMIC AND POLICY ISSUES

A wide range of socio-economic issues have to be resolved before hazard abatement decisions can be fully implemented. Questions related to hazard abatement range from the concerns about dislocating the residents of the old multiple dwelling unit housing, where rents are usually low and the occupants poor, to the concerns about requiring the building owners to invest in hazard abatement, particularly when the rate of return on such investment is below that of other opportunities. While such pragmatic questions must find practical answers, the basic issues must be addressed first. These can be divided into two categories.

1. What is the value society wishes to put on reducing natural hazards in our buildings? The values should be examined not only in economic terms of reducing future expenditures on disaster relief, but also in social terms of improving both the safety and the quality of built environment. In answering this question a better assessment of costs and potential benefits must be carried out.

2. If potential benefits of the hazard abatement program can justify the cost, how should the cost of hazard abatement be financed? This question involves both the amount of investment, as well as the criteria for priorities of allocating funds to different categories of vulnerable buildings, and the mechanisms for stimulating such investment in a free market society.

Studies addressing these issues are now just being initiated. These studies must include pilot projects dealing with actual communities so that realistic policies can be formulated regarding hazard abatement.

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2. "Community Safety Plan for the Comprehensive Plan of San Francisco", A Proposal for Citizen Review, San Francisco Department of City Planning, July 1974.

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ARCHITECTURAL RESTORATION FOR SEISMIC SAFETY

John C. Worsley, FAIA

CONTENTS

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ARCHITECTURAL RESTORATION FOR SEISMIC SAFETY

INTRODUCTION

The technical engineering aspects of seismic design will be covered in precise detail in other presentations. This report will emphasize the non-engineering problems which face an architect trying to structurally strengthen an historic building. The main thrust of this report is to explain a process which integrates the necessary elements of planning and construction that are essential in restoration/preservation work. This process may be of interest for inclusion in professional practice or construction management curricula.

HISTORIC PRESERVATION

Historic Preservation at the beginning of the 20th century was concerned with saving buildings or monuments which were important because of who had been born there, lived there, or because of a significant historical event which took place there.

Today, historic preservation has a much broader interest. The historian and the preservationist are attempting to preserve as much of the physical past as possible. Ordinary workers' homes in a coal mining town in Pennsylvania can interpret the real history of the mines and their families far better than a history book. Whole neighborhoods are being preserved as a means of saving history and revitalizing decaying urban centers.

The level of historical accuracy may vary in a given restoration project.

MUSEUM QUALITY

Museum quality restoration attempts to recreate a structure exactly the way it was during a given period in time. In this case, the restored building is a museum in which the accuracy of detail is extremely important. Museum type restoration entails precise recreation of the total environment as it originally existed. This includes the low lighting levels, lack of modern conveniences, and sometimes present day code violations if one applies a literal application of the law.

RESTORATION FOR ORIGINAL USES

Restoration for original uses includes such buildings as State Capitols, office buildings, stores and housing - both single family and multiple. This level of restoration has to meet current struc-

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tural and fire and life safety codes. This code requirement forces some compromises. If the office space is to be a working environment, then it is essential that the life support systems meet present standards. The restoration architect then must conceal the 20th century conveniences and retain the original architecture with a minimum of disruption of the historical character. This is a most difficult design task, since judgments must be made which can either change the historical message of the building or diminish the utility of the building. It is very tempting to rationalize an "improvement" on the original design. Combine this temptation with the very real need to make an old building conform to code and retain its old form, and you can begin to understand the intricate tapestry which the restoration architect must re-weave. In places, the threads are rotten. In places, whole scenes are torn out and new fabric is required. This is when the architect must restrain his creativity for new design and accept the role of recreator of the past. Writers change history to suit current fashion of morality or political philosophy. A restoration architect should have the building speak for its original self - warts and all.

RESTORATION FOR ADAPTIVE USES

Restoration for adaptive uses leaves the architect and engineer considerably greater flexibility in design. Generally, these buildings are in danger of destruction and the adaptive use provides a financially sound basis for recycling the structure. The recent Boston City Hall Renovation is such an example. The exterior was saved and the site was saved, but the interior was lost. In terms of historic preservation and the message the building interiors might have had, the Boston City Hall is gone. In its place is an interesting building stuffed inside its walls. The Boston City Hall and countless recycled warehouses and factories represent the largest volume of restoration work. These adaptive uses also provide architects with the greatest opportunity to demonstrate their individual design virtuosity and cleverness. It is very tempting when faced with restoring a building to decide that adaptive use is the proper treatment. Economic arguments can be developed as a rationalization for giving the architect a chance to do his thing. Adaptive use is proper when the need for the original use no longer exists. Good adaptive use retains as much of the original building form and message as is possible.

IMPACT OF BUILDING CODES ON PRESERVATION

Structural needs of historic buildings in seismic zones are vastly different than those in areas where only vertical loads are considered. Often, the easiest way to brace the historic building would be to add nonhistoric elements which would change the original configuration of the structure. The challenge to the architect is to devise a way to reinforce the historical elements in place and add no additional walls or visible braces. In addition, it is often required to hide mechanical and electrical systems within the original dimensions of the finish surfaces.

The regulations of the Occupational Safety and Health Administration (OSHA) are frequently in direct conflict with the objectives of restoration. The steepness of a stair, the lack of headroom in some spaces, can all be OSHA violations, but if they are corrected, the interpretive value of the building is lost. Most California architects have found OSHA administrators to be among the least cooperative public agencies in dealing with historic buildings.

Federal and State laws require that most public buildings be accessible to the physically handicapped. In historic buildings it requires ingenuity to provide access without destroying the historical integrity of the building. Most laws provide that literal interpretation for access may not be necessary if there is no reasonable use likely by the handicapped or if equal facilitation can be provided elsewhere.

Fire and panic regulations are concerned with:

1. fire protection of structural systems.
2. flame-spread ratings of finish materials.
3. exiting from building.
4. detection and protection systems.
5. occupant loads.
6. occupancy.

If an historic structure was built of materials which do not meet current fire protection laws or the exiting requirements, then it is often possible to adapt the use of the building through a change in occupancy or a limit in occupancy. Detection and protection systems can be designed into a building in a concealed manner so the historical integrity of a building is maintained and the intent of the safety regulations is met. This can best be accomplished by early meetings with the fire protection authority. In most cases, the fire marshal can be very helpful to an architect and owner if brought into the project soon enough.

Historic building codes have been established in a number of states. In most cases, these codes are permissive, in that they permit the building official and others to vary from a strict adherence to the letter of the law. In general, this involves a cooperative effort between owner, architect and building official to meet safety needs with a minimum compromise insofar as historical accuracy is concerned. As in the case of fire protection, early involvement of the building official is essential.

POLITICAL AND ECONOMIC IMPACTS ON HISTORICAL PRESERVATION

Publicly owned structures can often be inadequate on a seismic basis, since such buildings tend to remain in use much longer than commercial structures. In some cases, publicly owned buildings are built without regard to building codes, although this practice is largely being abandoned by most political entities. When public buildings reach a certain golden age, there is usually pressure from society to preserve these structures for posterity. The decision to save or not save public structures is political, and often architects become involved. An architect who understands seismic design as well as historical significance can make a valuable contribution to his community. Detailed design of structural elements is not essential, but the ability to analyze seismic forces and how the structure can be adapted to meet those forces is essential for an architect involved in preservation work.

Privately owned structures are usually saved when an economic basis for their survival can be found. In most instances, adaptive uses have to be found. The creativity and imagination of architects can be a major force in finding ways to give historic structures a second or third life. With the need for conserving energy, recycling buildings is receiving more cooperation at city hall. Restoration of private structures is going to be much more common in the future and architects should have in their education a significant exposure to the problems and the process of restoration.

DESIGN PROCESS

In new construction, the traditional role of the architect is to prepare plans and specifications which become instructions to the builder. In preservation work, it is necessary to have a team effort which includes owner, architect, historian, contractor and engineers. The addition of the contractor to the design effort is essential. In large projects, the owner may want to obtain the services of a technically trained person to represent his interest. In the restoration under way at California's State Capitol, the owner is Joint Rules Committee and the owner's representative is an architect whose role is coordination of the other team members' work.

THE ROLES OF TEAM MEMBERS

The prime responsibilities of each team member are as follows:

1. Owner - establish goals, program and budget. Coordinate other members' activities and provide timely approval of other team members' work.

2. Historian - research records to determine what the appearance of the building was at the period selected for restoration. Many older buildings have been remodeled so many times that the existing structure may not be historically accurate. Many fine old buildings have suffered devastation in the name of "modernization".

3. Architect - translate the findings of the historian into architectural drawings. The traditional schematic, design development and contract document phases are followed, but when structural rehabilitation is involved, there is not a clean cut separation of these phases.

   The steps in development of architectural planning usually include the following phases:

   A) As-Built Record Drawings. These drawings reflect the "as-found" condition of the building. They include historic and non-historic parts of the building.

   B) Catalogue Drawings. These are developed from the record drawings. Each historic door, frame, window, frieze or whatever, is assigned a catalogue number on these drawings. The numbers are attached to those elements to be removed and replaced. Items which cannot be saved are photographed, molded or recorded in whatever fashion is necessary to accurately recreate the item. In large projects, this catalogue information may be stored in a computer.

   C) Preliminary Drawings. These are very similar to standard preliminary drawings, except they have the architectural elements less defined and the structural parts more advanced.

   D) Working Drawings and Specifications. All of the information from the catalogue drawings is incorporated in the working drawings, including precise location of historic elements.

4. Structural Engineer - the structural engineer must find an engineering solution which will have a minimum impact upon the historical character of the building. This may mean putting a new structure inside the original building, and at the same time keeping historic dimensions of rooms as well as leaving space for 20th century life support systems.

5. Contractor - the contractor is responsible for the method of construction to be used in achieving the desired results established by the other team members. He is responsibile for the safety of the structure at all times. He is responsible for the custody of artifacts during construction. Because of these responsibilities, the contractor should be involved in the design process. A skilled contractor can

help a project design team immensely. In many cases, the method to be used in structural rehabilitation can change a design and reduce costs.

Although these are the primary responsibilities for each of the team members, the best results will be obtained if each member can be encouraged to step out of his traditional role and present ideas related to another team members' "turf". This kind of brainstorming takes some getting used to by the participants, because professional people tend to be defensive about their own specialization. The design team for the California State Capitol had some bruised egos for awhile, but as each person came to know the others, a cautious respect developed. The results obtained have been superb and could never have been accomplished using traditional methods.

HISTORICAL VS. OTHER DESIGN REQUIREMENTS

The design team should meet regularly. Once a week is a good interval. The meeting should start early in the day with no other activities scheduled for that day. Minutes kept by the architect set an agenda, and when other activities such as structure are being considered, that representative should record related discussions and decisions.

The normal coordination problems in a new building are magnified many times in restoration work. Dimensions are fixed historically without any provision in history for a seismically resistant structure or central heating or cooling or plumbing. Instead of whale oil lamps, we have electric lights. These lights must produce acceptable levels of illumination in work areas and have an acceptable historic design.

All of this requires compromise. Sometimes history is compromised, sometimes energy conservation loses a little, but the structural integrity of the building cannot be compromised, nor can the utility of the restored building if it is to be used for modern day activities. Compromise, with all team members being advocates for their point of view, is the material for resolution of these problems.

CONSTRUCTION PROCESS

CONTRACTING METHODS

Contracting methods used for new construction present problems when an owner wishes to restore or preserve an existing building. This is especially true when a structural strengthening for seismic purposes is also involved. There are many reasons for this.

1. Lack of information about existing structure to permit an efficient structural design.

2. Lack of information about existing structure to enable a contractor to develop an efficient method of construction.

3. Lack of information about what historical elements may be hidden behind latter-day remodeling. This lack of information may preclude an historically accurate restoration.

4. If an existing structure is to be restored, a low bidder removing structural elements prior to strengthening might very well destroy what should be saved.

5. Where historically significant materials should be saved and put back in a building, there is no way to write a "tight specification" to assure quality anymore than one can legislate morality.

The California State Capitol Restoration Project was exempted by law from the California State Contract Act. The contractor was selected on the basis of his qualifications. The construction contract has several phases:

1. Investigative

2. Design

3. Estimating

4. Construction

    A) Guaranteed Maximum Structural Sum
    B) Other work

Phases 1 through 3 are reimbursable at cost. The contractor receives a fixed fee for all work. The State provides all office space, supplies, equipment, gasoline, and miscellaneous services. Overhead on charges is limited to less than 5%.

The Guaranteed Maximum Structural Sum was negotiated between State and contractor with an incentive provision. Eighty percent of the savings on the GMSS are credited to the owner and twenty percent to the contractor.

To reduce contractor's cost of financing, payments are made weekly. Bills are presented and payment is made during the same week.

The philosophy behind the contract was to reduce the element of risk over which the contractor had no control. Insurance premiums were paid by the State, since they were able to get far lower rates.

There is a real necessity to apply the creative thinking of architects to the contracting problems of preservation and restoration. The largest area of contracting difficulty is the normal desire of owner and architect to thrust the responsibility for unknown conditions on a contractor. If an owner is willing to accept this responsibility and establish controls to verify costs and protect his interests, then realistic construction costs without large contingency factors can be the result.

In conclusion, the contracting method should evolve from the problem. The architect has the responsibility to define the problem and document it in a written program.

PHASING OF CONSTRUCTION

Proper phasing of a preservation/restoration/seismic strengthening project is essential. In the case of the California State Capitol, the problem was seismic. Without a seismic/structural problem, there would have been no project. With the problem, there was an opportunity to return to California an important part of its cultural heritage which had been mindlessly destroyed over many years. The human erosion to the building took place over 100 years and no one knew what was happening until suddenly the Capitol was architecturally devastated as well as structurally unsafe.

In an historic/restoration/strengthening, the first decision is how to meet the structural needs including seismicity. An architect has to be able to deal with the architectural implications of structure on a much more intimate and detailed scale in restoration projects. The 12" minimum concrete dimension of your engineer will have to be considered early in the project. Architectural and historical compromises must be recognized in the proposed structural solutions <u>before</u> they are formalized in architectural drawings.

In general, the order of the design process for seismic/restoration/preservation is as follows:

1. Structural/architectural

2. Mechanical/electrical/architectural/structural

3. Architectural

All phases of design relate back to architectural - even more than in a new structure.

The duct penetrations through shear walls, the electrical conduits in concrete must all be provided for in the structural design. This means that a very precise preliminary layout of mechanical and electrical is essential at a very early stage of design. Architectural design in one sense follows some of the structural and mechanical/electrical decisions. To ensure the desired architectural and historical result, the architectural implications of structural, mechanical and electrical solutions must be recognized by the architect.

Compromises have to be made constantly, but they should be made with full knowledge that compromise is taking place not by default when it is too late to change.

By intelligently phasing the construction, fast-track methods can be applied to restoration work. While the structure is being rehabilitated, historical woodwork is being refurbished, architectural, mechanical and electrical plans, are completed. The savings of time are also savings in money. To prevent cost overruns however, it is necessary to have careful cost estimates for all work. These estimates need to be updated constantly as planning information becomes more definitive.

PREQUALIFICATION OF SUBCONTRACTORS

Prequalification of subcontractors is essential. Having a subcontractor on the job who cannot perform either on time or with the quality desired, can be very costly. It can also reduce the quality level desired for restoration/preservation work.

There are criteria for prequalification on the standard AIA form "Qualification of Contractors". Such items as financial capability, years of experience in similar work, size of average crews, client references etc. are essential in evaluating subcontractors. By prequalifying contractors, an owner is not in the position of having a low bid from a subcontractor who might not have the ability to perform.

SUPERVISION AND INSPECTION

Supervision of construction and inspection of the work on a restoration project with the type of contract described here, requires new attitudes and new roles for all members of the team.

Due to the concept of a reimbursable contract with shared savings, it is essential that the owner not have his inspectors act solely as enforcers. If savings are to be maximized, the owner also has to have his staff wear the hat of a facilitator. It is essential that accurate information be provided expeditiously to the contractor. To this end, the owner's staff has to walk a very narrow course between the traditional role of playing gotcha! And that of supervision which is the contractor's responsibility. The architect, engineer, contractor and owner are on the same side with this form of contract, and because of this, the "arms-length" approach used in most contracts does not exist. There is a danger that the owner may relieve the contractor of some of his responsibility, and the owner's representative must be alert to the actions of his staff.

CONCLUSION

Restoration/rehabilitation of historic buildings requires a new contracting procedure for both design and construction. In general, a team approach involving all disciplines, is the best method for achieving optimum results. By using this method, the objectives of structural, architectural and historical design can be addressed with the essential input of the contractor who is to build the building.

PLANNING AND DESIGN OF STRONG-MOTION INSTRUMENT NETWORKS

R. B. Matthiesen

CONTENTS

INTRODUCTION

The primary input for the design of strong-motion instrument arrays comes from the research needs in strong-motion seismology and earthquake engineering. The impetus behind much of that research is the application of the research results in engineering design and reduction of earthquake hazards. This input defines general objectives to be accomplished by an appropriately designed network but does not constrain the development of the network geographically. A secondary input comes from the mission-oriented and regulatory agencies that desire to monitor the response of critical facilities to assess their response during potentially damaging earthquakes. The location of this instrumentation is constrained to the specific structure or system being monitored but may add significant data to that obtained from a network of research instruments. The mission-oriented agencies also influence the design of the network through their need for additional research results on a timely basis.

The types of studies that utilize strong-motion data may be classified as follows:

- Studies of the source mechanism.
- Studies of the spectral characteristics of strong ground motion and of the variations of these characteristics with the nature of the source, the travel path and regional geology, or the local site conditions.
- Studies of soil failures such as soil liquefaction or landslides.
- Studies of the response of representative types of structures and interconnected systems at potentially damaging levels of response and of the influence of the foundation conditions of this response.
- Studies of the response of equipment which may be free-standing or mounted on structures.

The first of these studies is a fundamental study in seismology. The remainder conveniently divide into ground motion studies and structural response studies and may involve the use of instrumentation for either the research or monitoring function.

CRITERIA FOR NETWORK DESIGN

The development of criteria for the planning and design of networks and arrays of instrumentation to measure ground motions involves the following steps: (1) the ground motions must be estimated; (2) the costs of operations must be evaluated; and (3) the benefit to be derived from the data must be assessed. A similar process is also required as the first step in the process of planning instrumentation arrays for structures (Rojahn, 1976).

The estimation of ground motions involves a determination of the tectonic setting, the seismicity of the region, and the recurrence of strong ground motions. This is similar to the process of obtaining ground motions for use in analyses of seismic risk or for use in establishing design levels for critical facilities (Algermissen and Perkins, 1972; Hays, et al, 1975). In this basic approach to estimating ground motions, the source characteristics are modeled in terms of the recurrence of earthquakes of different magnitudes; the transmission of the motion is modeled as an attenuation of peak acceleration; and the motion at the site is obtained as a recurrence relation for particular site conditions (see fig. 1). More refined techniques are the subject of current research in which the source characteristics are modeled in terms of the expected stress drop and source dimension; the transmission of the motion is modeled in terms of the wave propagation, attenuation, and dispersion; and the site effects are modeled in terms of their influence on the spectral characteristics of the motion.

Several authors have gathered a considerable amount of data indicating that for appropriately large source regions, the recurrence of earthquakes of different magnitudes can be represented as straight lines on semi-log plots (see Algermissen, 1969, for example). On the other hand, the existing data on the attenuation of strong ground motions indicate that there is a considerable amount of scatter in the relation of the peak acceleration, velocity, or displacement to the distance from the source. Figure 2 presents the attenuation of maximum acceleration with distance from the source for all of the data recorded during the San Fernando earthquake (see Maley and Cloud,1971) An order of magnitude difference may be seen in the peak accelerations recorded at any one distance. Figure 3 presents the attenuation of peak accelerations with distance from the epicenter for all data recorded at Ferndale, California., during the past 40 years. A considerable amount of scatter is evident in this plot also. This large amount of scatter in the data casts some doubt on the validity of the simplified model of transmission of motion.

The availability of data from several stations that have been installed for about 40 years provides a more direct approach to the evaluation of the recurrence of strong ground motions. For example, the results obtained from Ferndale are shown in figures 4 and 5. In figure 4, the cumulative numbers of events for which peak accelerations exceeded selected levels are plotted versus the year in which the event occurred. The levels of peak acceleration used in figure 4 were selected to illustrate the approach used. Similar results can be obtained for each of the levels of peak acceleration recorded at this site. No attempt has been made to distinguish between foreshocks, main events, and aftershocks in compiling these data. Straight lines have been fitted to the data, and the slopes of these lines define the "events per year" for each of the selected values of peak acceleration.

All levels of peak acceleration from the complete set of records obtained at Ferndale were used to construct figure 5, in which the cumulative distribution of events per year is plotted versus the peak acceleration values. The end points are shown as circles in this figure, signifying an insufficiency in these data. (The value at a peak acceleration of 10 cm/sec^2 appears to be too low as a result of the fall off in the number of low level events that are recorded by an instrument that is triggered by the event being recorded, whereas the values for the highest peak accelerations are obtained from fewer than five events, and this is considered to be an insufficient amount of data). The amount of scatter in the data in figure 5 is relatively small compared with the amount of scatter indicated by the attenuation plots in figures 2 or 3.

Data of the type shown in figure 5 have been obtained for all of the strong-motion instrument sites that have been in place for about 40 years (table 1). Only in three cases (Ferndale, Hollister, and El Centro) are the data sufficient to provide statistically meaningful results for peak accelerations up to 100 cm/sec^2. Of equal importance, however, is the fact that at several sites in these "seismically active" areas, no estimate of recurrence could be made after 40 years of recording. For example, in the San Francisco Bay region, no reliable estimates of recurrence could be made for Golden Gate Park or San Jose, although a maximum value of greater than 100 cm/sec^2 has been recorded at each site. In the Los Angeles basis, no reliable estimates can be made for Westwood or Pasadena. Similarly, although 12 records have been obtained at Helena, Mont., only three of these have been recorded since 1940 and none since 1960. The results in California are in sharp contrast to other estimates of recurrence that yield equal rates along most segments of the San Andreas fault. These results are also an indication of the serious difficulties in any attempt to provide a rational plan for obaining the desired strong-motion records: potentially damaging earthquakes in any one area occur infrequently, and our basic understanding of the processes and recurrence of potentially damaging ground motions is therefore inadequate.

The cost of maintenance has been found to be about three times the cost of the instruments themselves (depreciated over a 20-year life). As a result, the procedures used in instrument maintenance need to be critically evaluated. In particular, the service interval may be lengthened if an evaluation indicates that this will not result in serious depreciation in either the quality or number of records recovered. The results of a study of the length of the service interval is shown in figure 6. In the early days of the program, a service interval of 2 months had been established. As the numbers of instruments being maintained dramatically increased in the late 1960's, this interval was perforce increased to 3 months. More recently, a general policy of servicing at a nominal 4-month interval has been adopted (a selected group of instruments are being serviced at 6-month intervals). Since the current cost figures are based on a nominal 3-month service interval, an increase to a 6-month interval will significantly decrease the maintenance costs, although they are not expected to decrease by half since it is planned that more time should be spent at each instrument when the service interval is lengthened. As a part of the evaluation of maintenance procedures, all of the older instruments are being replaced with modern instruments, and the modern types of instruments in service are being modified to bring them up to present specifications. This upgrading of the instruments should raise the lower of the two sets of lines shown in figure 6.

From the recurrence data summarized in table 1 and the average costs of instruments and maintenance ($400 per year), the costs per record for records with peak accelerations greater than specified amounts can be obtained (see table 2). At most sites, the cost doubles as the level of peak acceleration doubles. Estimates of these costs for other sites must be determined if planning criteria are to be firmly established. Since peak accelerations on the order of 200 cm/sec^2 are the minimum levels of potentially damaging motions, significant costs must be anticipated if we are to record potentially damaging levels of ground motion at many of these sites.

The benefits that will be derived from the data that will be obtained must be estimated in order to assess the proper significance of these costs. Obviously, the first set of data that will permit some of the unanswered questions regarding the nature of the strong ground motions from earthquakes in the eastern part of the United States will be of considerable benefit, whereas additional records at 50 cm/sec^2 obtained at many of the sites in California are of little benefit. It is clear, in general, that those studies that can be accomplished in the more active areas may cost one tenth as much as they would in other areas of California. Thus, studies of local site effects should be planned for Ferndale, Hollister, and El Centro, if the local soil conditions permit. Studies of low-rise buildings can be conducted only in San Francisco or Los Angeles.

GENERAL OBSERVATIONS

Most of the strong-motion records obtained to date have been obtained in California, and the techniques for estimating ground motion spectra are largely based on these records. Preliminary evaluations for other regions of the United States suggest that the Mississippi embayment may provide as much data, and as inexpensively, as some of the less active areas of California. On the other hand, high maintenance costs in Alaska offset the advantage of the generally high level of activity in that region.

General information on the influence of local site conditions on the spectral amplitudes of ground motion may be obtained from the regional networks by placing instruments in different geologic settings or at sites with different soil conditions. More detailed studies will require an expensive instrumentation program including down-hole instruments. These should be conducted in regions where the seismic activity is sufficiently high to insure an adequate return on the investment in instrumentation and its maintenance.

Similarly, instrumentation designed to study soil failures through liquefaction or landsliding can be incorporated into the regional arrays if areas subject to soil failure are identified. Remotely recording instruments should be placed on the area of potential landslide or liquefaction as well as on nearby stable ground. Extensive instrumentation for these studies should be installed only in highly active areas.

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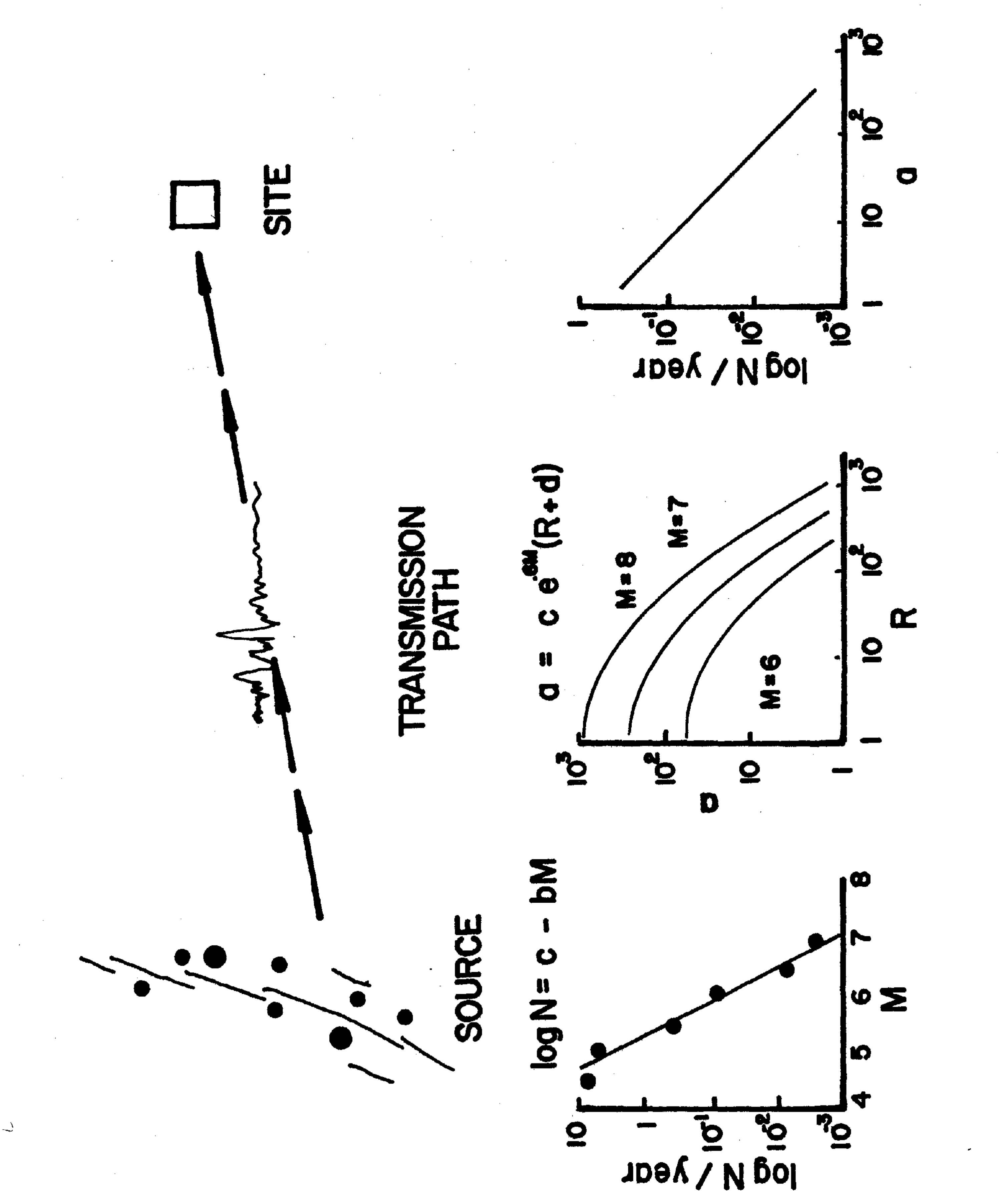
Table 1 - Recurrence times for stations installed for 40 years

Total Number Years	Number of Records	Maximum Accel cm/sec^2	Station Location	Years/Event a > 25	a > 50 (a in cm/sec^2)	a > 100
40	45	274	FERNDALE	1.5	3	6
40	11	230	EUREKA	8	(15)	-
40	3	124	GOLDEN GATE PARK	-		
39	6	52	ALEXANDER BUILDING	(20)	-	
39	11	48	SOUTHERN PACIFIC BLDG	(10)	-	
40	6	45	OAKLAND CITY HALL	(12)	-	
40	6	56	BERKELEY	(15)	-	
41	4	138	SAN JOSE	-		
30	32	191	HOLLISTER	2	4	8
40	9	172	SANTA BARBARA	10	-	
40	3	100	WESTWOOD	-		
40	7	220	HOLLYWOOD	(30)	-	
40	9	110	OCCIDENTAL BLDG	14	-	
41	11	210	VERNON	10	20	-
41	10	250	LONG BEACH	10	(25)	-
40	4	100	PASADENA	-		
40	10	46	COLTON	12	(25)	-
41	24	314	EL CENTRO	3	6	12
41	9	30	SAN DIEGO	(20)	-	
40	13	38	BISHOP	8	-	
36	7	42	HAWTHORNE	10	-	
38	12	115	HELENA	-		

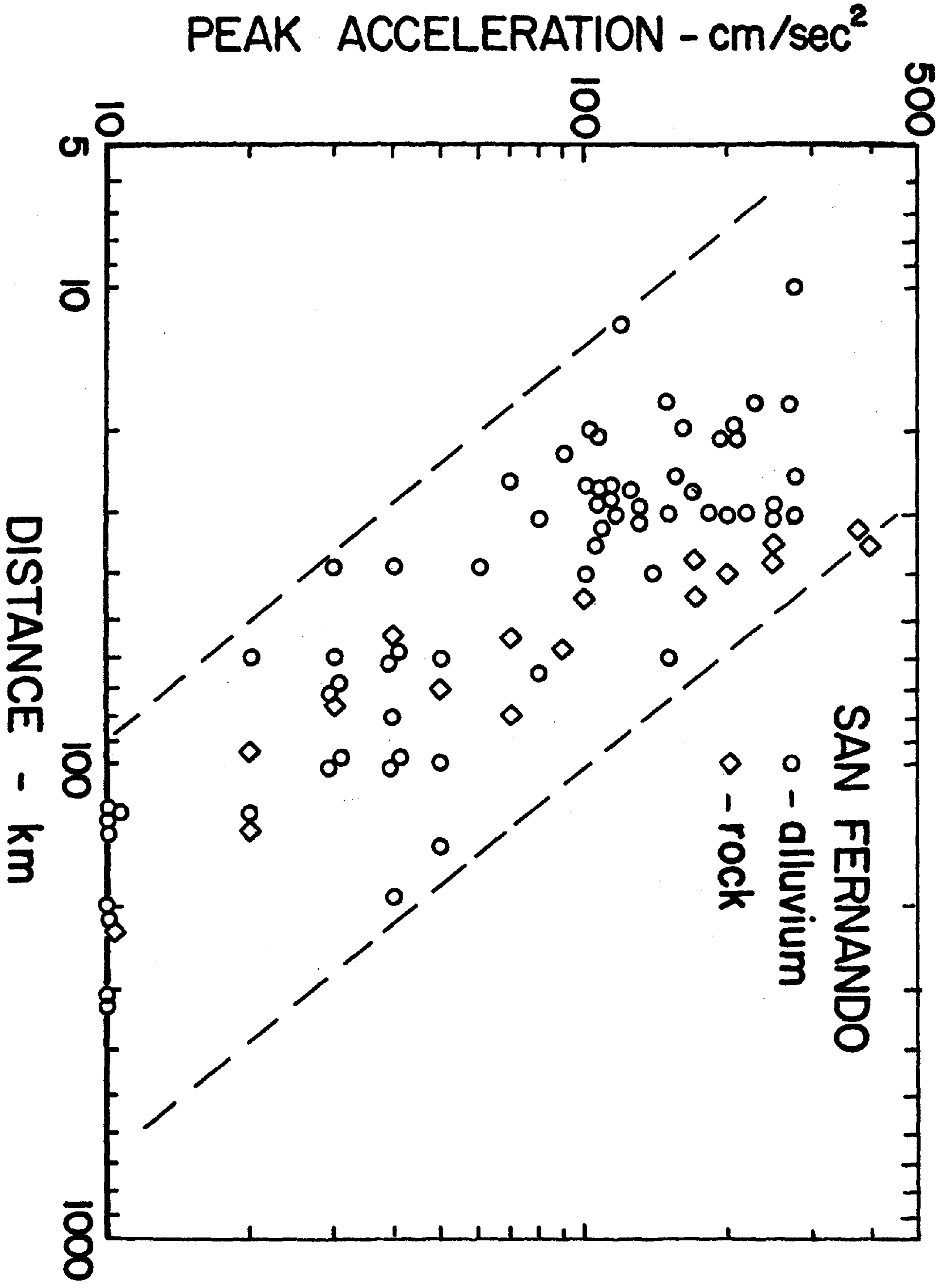
Table 2 - Summary of costs per record

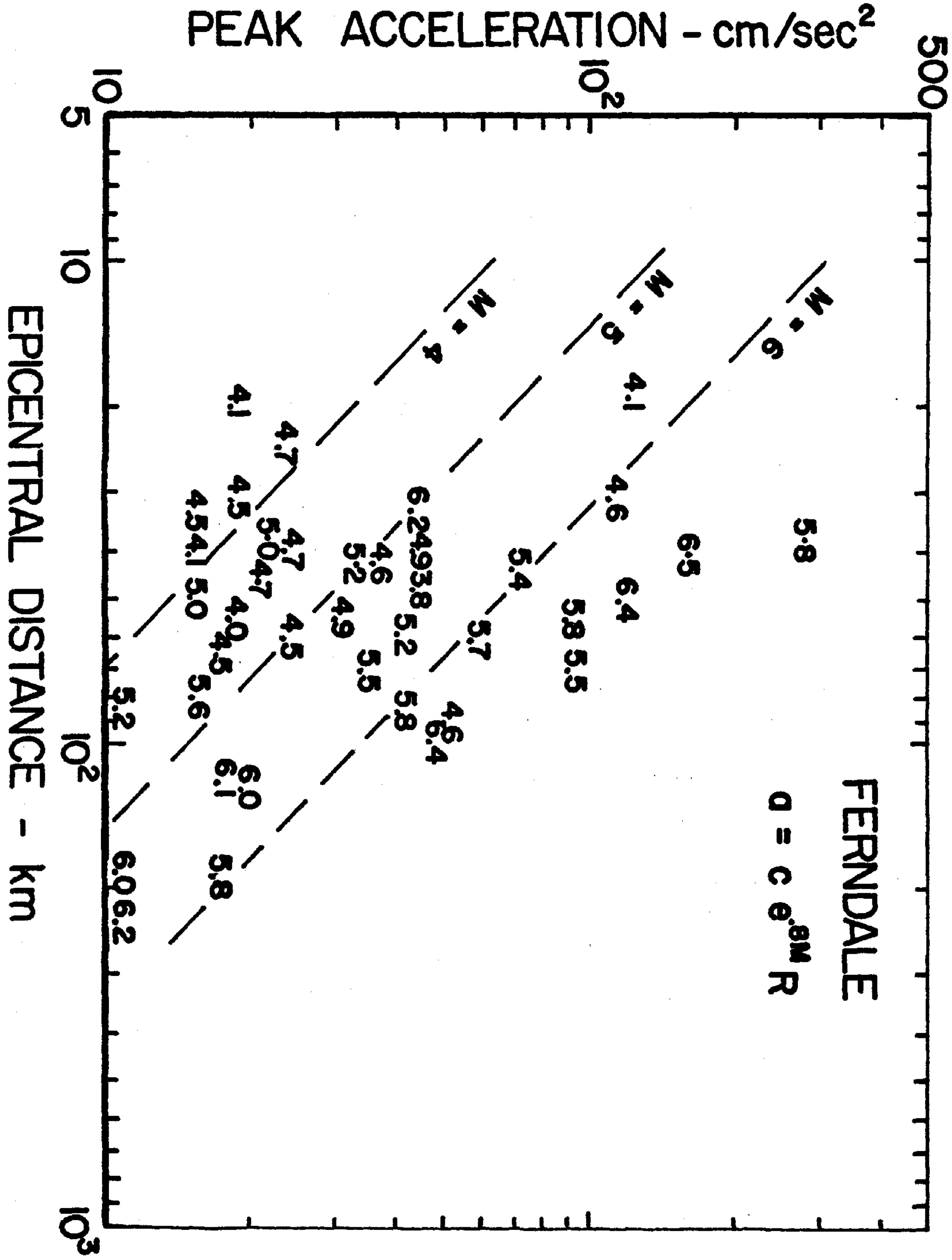
Station Location	Maximum Accel cm/sec^2	Cost/Record in Dollars a > 25	a > 50	a > 100
		a in cm/sec^2		
FERNDALE	274	600	1200	2400
EUREKA	230	3200	(6000)	-
GOLDEN GATE PARK	124	-		
ALEXANDER BUILDING	52	(8000)	-	
SOUTHERN PACIFIC BLDG	48	4000	-	
OAKLAND CITY HALL	45	(4800)	-	
BERKELEY	56	(6000)	-	
SAN JOSE	138	-		
HOLLISTER	191	800	1600	3200
SANTA BARBARA	172	4000	-	
WESTWOOD	100	-		
HOLLYWOOD	220	(12000)	-	
OCCIDENTAL BLDG	110	5600	-	
VERNON	210	4000	8000	-
LONG BEACH	250	4000	(10000)	-
PASADENA	100	-		
COLTON	46	5000	(10000)	-
EL CENTRO	314	1200	2400	4800
SAN DIEGO	30	(8000)	-	
BISHOP	38	3200	-	
HAWTHORNE	42	4000	-	
HELENA	115	-		

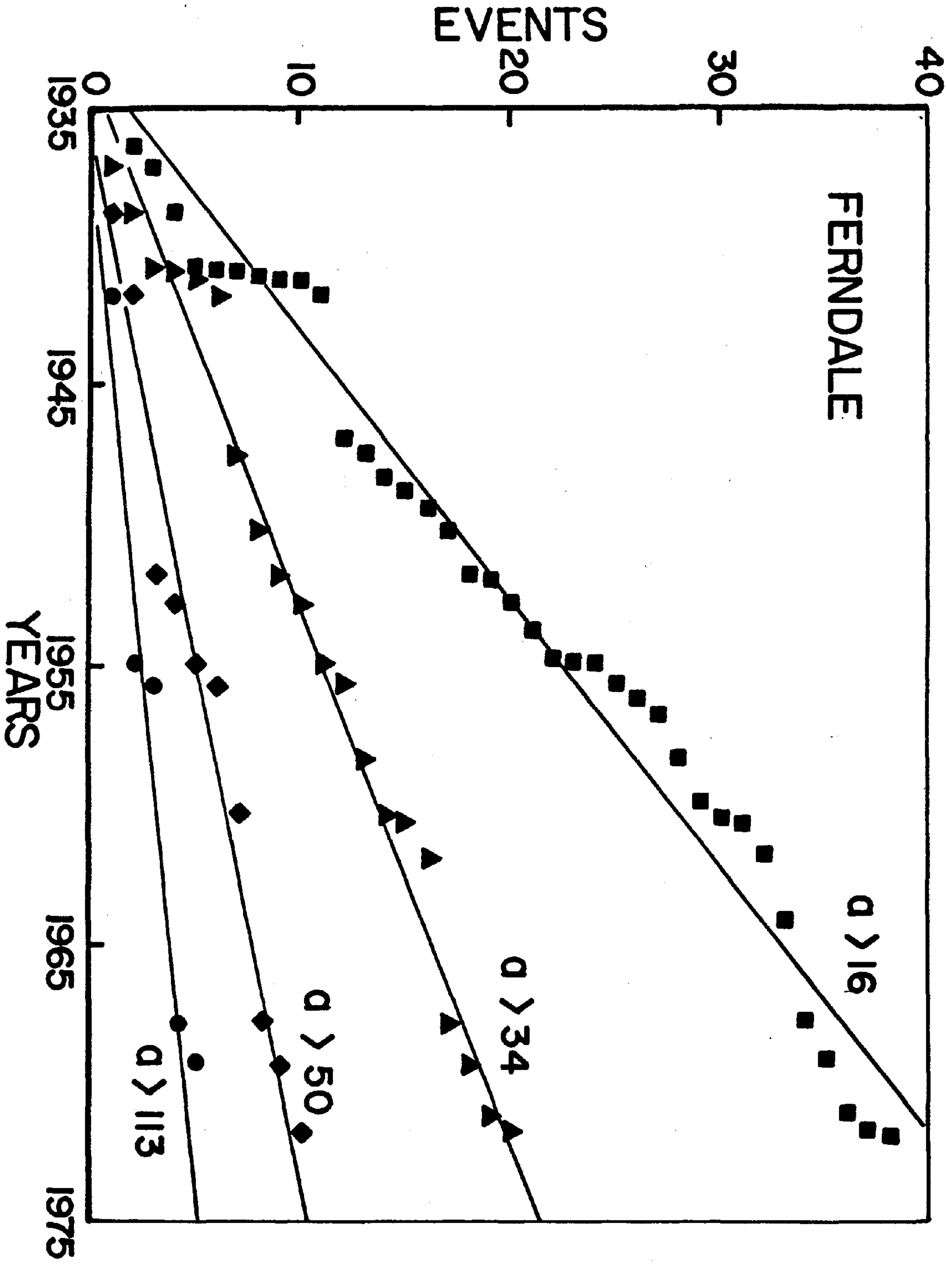
FIGURE TITLES

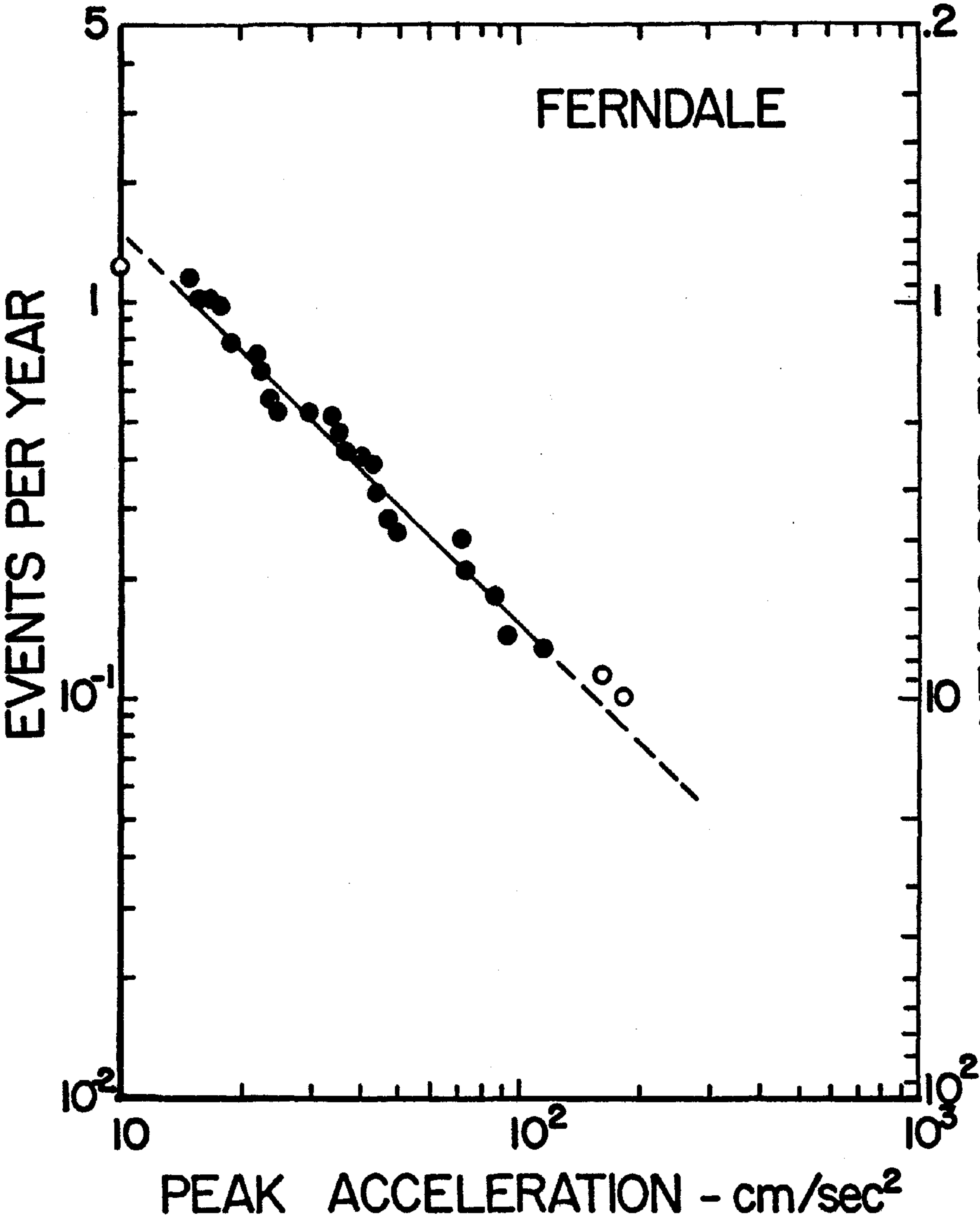


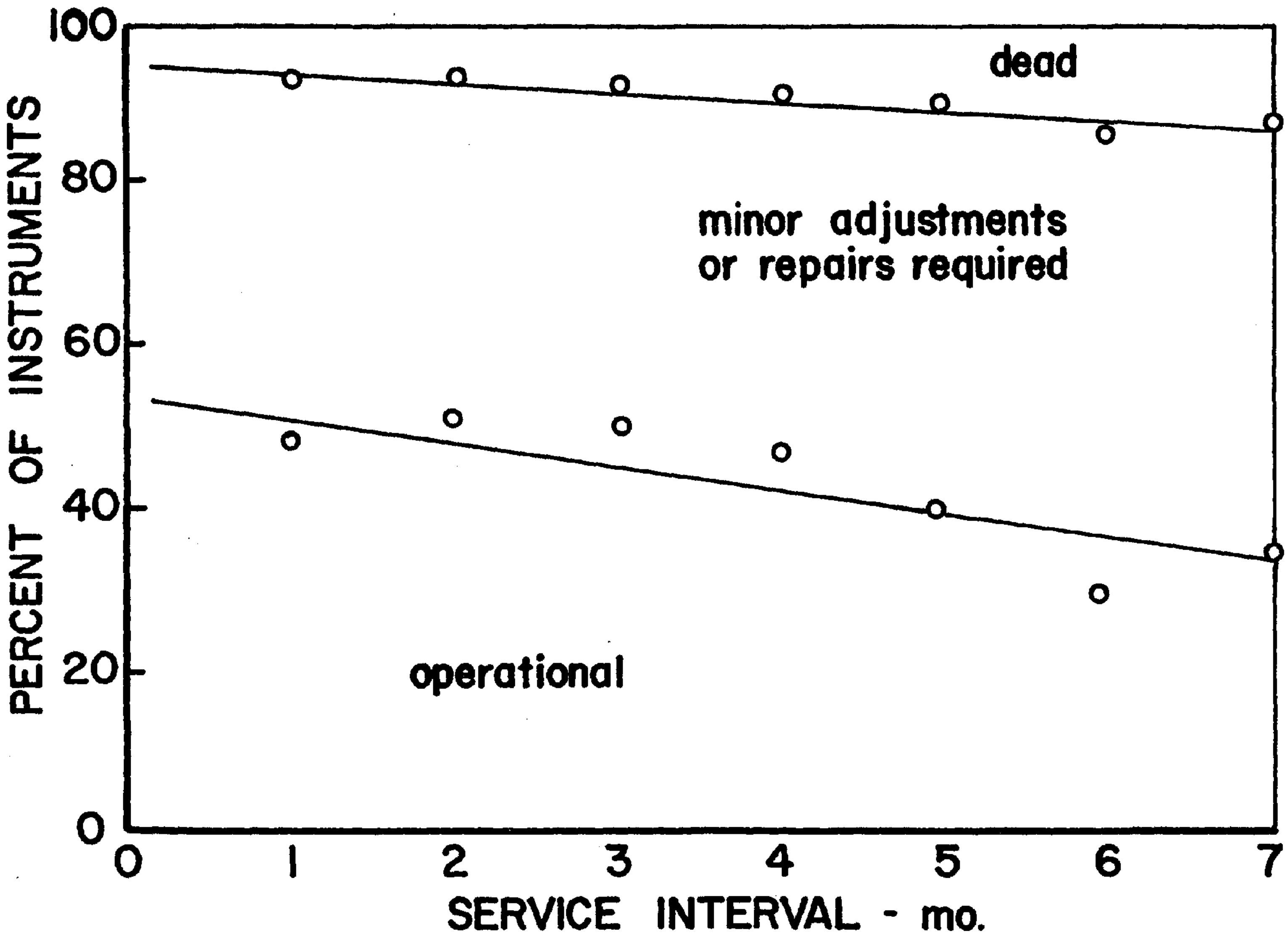
SOURCE
TRANSMISSION PATH
SITE
log N = c - bM
log N / year
M
a
R
M=8
M=7
M=6
log N / year
a


PEAK ACCELERATION - cm/sec²
500
100
10
5
10
100
1000
DISTANCE - km
SAN FERNANDO
o - alluvium
◇ - rock


PEAK ACCELERATION - cm/sec²
EPICENTRAL DISTANCE - km
FERNDALE
M = 6
M = 5
M = 4


FERNDALE
EVENTS
YEARS
0
10
20
30
40
1935
1945
1955
1965
1975
a > 16
a > 34
a > 50
a > 113


FERNDALE
EVENTS PER YEAR
YEARS PER EVENT
PEAK ACCELERATION - cm/sec²
5
1
10⁻¹
10⁻²
.2
1
10
10²
10
10²
10³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SEISMIC PUBLIC POLICY AND THE DESIGN PROFESSIONAL

Karl V. Steinbrugge

CONTENTS

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SEISMIC PUBLIC POLICY AND THE DESIGN PROFESSIONAL

INTRODUCTION

The design professional, be that person an architect, engineer, or other involved in the design of buildings, is constantly confronted with laws, codes, regulations, and other instruments of public policy. Many of us have rather strong adverse positions regarding certain details of building codes and the like, although it can be shown that our own design professions may have had major inputs when the regulations, etc. were established.

When stipulated by public policy, earthquake hazard reduction requires design responses from the architect among many others. Often the architect as leader of a multidisciplinary team can greatly hinder or help the overall effectiveness of seismic safety in the design of a particular structure. The whole intent of this Institute, of course, is to improve the effectiveness of the architect in his design leadership role.

Seismic public policy reflects, or should reflect, the wishes of the public. This is not a simple process since the public does not understand the technical problems, their elected representatives often do not have adequate time to study the problems, and the multiagency overlaps, or gaps, on specific problems hamper even the best of bureaucracies. The California solution has been the establishment of its Seismic Safety Commission.

The main thrusts of this paper are twofold, with both being from the viewpoint of the architect's potential roles:

1. Using California and its Seismic Safety Commission as an example, examine the historic background of public policy, Commission accomplishments to date, and its role in solving new public policy problems.

2. Identify particular multidisciplinary problems for which the knowledgeable architect can make significant contributions towards their public policy solutions.

PUBLIC POLICY THROUGH THE 1960s

With rare exceptions until recent years, developments in seismic design have had no more than minimal direct relationships with policies established by elected officials or by senior appointed officials. Implied public policy was to build "safe" structures, with large segments of the public too often believing this to mean being "perfectly safe in an earthquake-proof structure." One might cite as an example California's Field Act which covers public schools. But in recent years, public policy attention has been given to the meaning of safety, need for certain buildings to remain functional after an earthquake, and responses to disaster after it strikes.

It is appropriate to briefly review California's background of public attitudes towards the seismic hazard and their consequences on public policy. Professor Andrew Lawson, writing in the March 1911 issue of the <u>Bulletin of the Seismological Society of America</u> stated:

> .....In the present state of public opinion in California, for example, it is practically impossible to secure state aid for the study of earthquakes. The commercial spirit of the people fears any discussion of earthquakes for the same reason as it taboos any mention of an occurrence of the plague in the City of San Francisco. It believes that such discussion will advertise California as an earthquake region and so hurt business.....(p.3)

In the years which followed the 1906 San Francisco disaster, the press generally referred to the event as the "1906 fire", with rare reference to the earthquake which caused the fire. San Francisco building code regulations, strengthened with respect to lateral forces after the 1906 earthquake, were reduced as years passed. Public policy was to downplay the hazard just as Professor Lawson had written in 1911.

San Francisco was not alone in this ostrich-like viewpoint. A book published in 1928 by the Southern California Academy of Sciences stated in its summary of conclusions:

> .....The accumulative weight of data substantiates beyond a doubt my deduction that Los Angeles is in no danger of a great earthquake disaster. (p. 227)
>
> The City of Los Angeles is remotely situated from the three lines of maximum seismicity in California.....(p. 227)

The 1933 Long Beach earthquake turned this book into a collector's item. After the Long Beach shock--and to southern California's credit--public policy recognized the hazard in the form of lateral force provisions in local building codes; these provisions were substantially superior to anything heretofore enacted in the United States. The State of California also responded with its well-known Field Act which resulted in vastly stronger public school buildings.

Coming back to northern California, the City of San Francisco officially ignored the hazard in its building code as did most (but not all) of the other jurisdictions in the metropolitan San Francisco area; this situation continued until almost 1950.

In the years since 1950, the interest in earthquake hazard reduction has increased rapidly throughout California. The state's worldwide leadership in the development of earthquake provisions in building codes became evident in the period between 1956 and 1960 through the efforts of its design professionals. Additionally, within the past decade the subject of hazard reduction has received remarkable interest throughout the United States stimulating further efforts in California. Over the past 20 years, this interest has been largely confined to civil and structural engineers, except for certain outstanding individuals among architects, geologists, and seismologists. Prior to 1964, virtually no attention was paid to the subject by social scientists.

Until recently, effective Federal support has been token-to-minimal in earthquake hazard reduction programs despite numerous reports issued by various agencies, interagency groups, and outside organizations. This situation has been slowly but noticably improving since the 1964 Alaskan earthquake, with a very major increase probable for this year. Indeed, the current bill (S.126) by Senator Cranston proposes $220 million over a three-year period. Alternate bills have similar amounts. The Administration's position is favorable. It is reasonable to conclude at this writing that substantial funding will become a reality. This will have a major impact on numerous aspects of developing public policy.

Recent earthquake experience in the United States -- such as that gained from the earthquakes in Alaska in 1964, Santa Rosa in 1969, and San Fernando in 1971 -- has shown that certain earthquake hazard problems exist which require the attention of many disciplines in addition to those of architecture and structural engineering. This experience shows that the design professionals did, in general, design and construct buildings that were adequately safe for the large majority of their occupants during an earthquake. Perfection was not achieved, and a substantial number of casualties could occur in a future earthquake from the small percentage of modern buildings which are expected to collapse or be severely damaged for a variety of reasons. Additionally, the problem of building evacuation for a fire following an earthquake is becoming increasingly significant as the height and number of high-rise buildings increases.

The current philosophy of earthquake resistive design, as expressed as public policy in building codes, states in part:

> Resist major earthquakes, of the intensity of severity of the strongest experienced in California, without collapse, but with some structural as well as nonstructural damage.

Obviously, examples such as the collapse of the Four Seasons apartment house in Anchorage after the 1964 Alaska shock, the significantly damaged Social Service Building after the moderate Santa Rosa shock of 1969, and the nearly collapsed, multistory Olive View Hospital after the moderate San Fernando shock of 1971, show that significant engineering and scientific problems still remain to be solved.

CURRENT LEADERSHIP IN CALIFORNIA PUBLIC POLICY

Significant changes in public policy do not always follow a disaster, as was evident after 1906. However, since the 1971 San Fernando shock, public policy changes have reflected the changing public attitudes in California, and the full significance of some of these changes undoubtedly are not yet fully understood by all design professionals. The principal changes made shortly after the 1971 earthquake were embodied within enacted legislation introduced by Senator Alquist and others of the California Legislature's Joint Committee on Seismic Safety. Executive actions also resulted from recommendations by the then Governor's Earthquake Council. Continuing efforts are being carried out by California's Seismic Safety Commission, being the successor body to the Legislature's Joint Committee on Seismic Safety and the Governor's Earthquake Council.

Currently, California's Seismic Safety Commission has the overall state mandate with respect to public policy. Its enabling legislation was signed into law by the Governor on September 26, 1974, but the Commissioners were not sworn in until May 27, 1975. Since then, one of the major chores of the Commission has been to carefully examine the effects of the numerous laws passed after the 1971 San Fernando earthquake, with the intent of this review being to measure their effectiveness and shortcomings, if any. Since most of the current Commissioners were also advisors to its predecessor organizations, this analysis has the promise of being concise evaluations of recent changes in public policies. Other subject areas are being explored and these will be discussed in a following section.

Certain aspects of the Seismic Safety Commission are unusual and warrant mention. First, it does not have "line authority." This means that the Commission does <u>not</u> administer programs, does <u>not</u> act in any significant regulatory position. Its role is to concern itself with overall public policy, concern itself with agency discharge of their hazard reduction responsibilities, and concern itself in an oversight capacity (namely, identifying problems for which no,or inadequate,attention is being given). To be effective in these capacities, it cannot, and is not a part, of any agency; it therefore is a Commission which reports directly to the Legislature and to the Governor.

The Commission has 17 members, one being a Senator, one being an Assemblyman, with the remainder from various disciplines including architecture, planning, and engineering.

Specifically, the enabling legislation specified the following duties for the Commission, among others:

(a) Setting Goals and priorities in the public and private sectors;

(b) Requesting appropriate state agencies to devise criteria to promote seismic safety;

(c) Recommending program changes to state agencies, local agencies, and the private sector where such changes would reduce the earthquake hazard;

(d) Reviewing reconstruction efforts after damaging earthquakes;

(e) Encouraging research; and

(f) Helping to coordinate the seismic safety activities of government at all levels.

To implement the foregoing responsibilities, the Commission may:

(a) Review state budgets and review grant proposals;

(b) Review earthquake-related legislation proposals, to advise the Governor and Legislature concerning such proposals, and to propose needed legislation; and

(c) Recommend the addition, deletion, or changing of state agency standards.

SIGNIFICANT CHANGES IN PUBLIC POLICY

Some of the post-1971 legislation will undoubtedly have significant impacts on society as well as on architects and planners. A brief review of several pieces of this legislation warrants attention.

HOSPITAL SAFETY

A very significant change in public policy is included in the legislation by which the state pre-empted new hospital construction from local control. It is of little point to spell out the technical details of this legislation other than to state that it followed the precepts of the State of California's Field Act for public schools plus the following statement which is of major significance:

> It is the intent of the Legislature that hospitals, which house patients having less than the capacity of normally healthy persons to protect themselves, and which must be completely functional to perform all necessary services to the public after a disaster, shall be designed and constructed to resist, insofar as practicable, the forces generated by earthquakes, gravity, and winds......

It is important to note that the basic earthquake design concept expressed earlier in this presentation (namely, that buildings may suffer significant damage in a great earthquake and, by implication, no longer remain functional) is no longer an acceptable level of risk for new hospitals in California. Future seismic design must include, among many other items, the consequences of relative motions between floors. Some of the features which are requiring special seismic design attention are elevators, stairs, air-conditioning and heating systems, water supply, electrical power, communications, and medical supplies. Potential damage to smoke-tower wells which could allow fire to spread upward through multistory buildings obviously requires attention. The intent of the legislation does not state that the hospital must remain "undamaged," but it must only remain "functional" in order to perform all necessary services. Clearly, the intent of the law requires inputs from many disciplines: Architectural, civil, structural, mechanical, electrical, fire protection, and geological, among others.

The concept of hospital buildings remaining "completely functional" during, and also subsequent to, an earthquake is being considered for other types of occupancies vital to the public after a disaster. Specifically, consideration is being given to the introduction of legislation which will extend this concept of functional adequacy to other kinds of emergency service structures such as fire stations and disaster command posts. (Alameda County has the dubious distinction of having an underground disaster command post located within the seismically active Hayward Fault zone.) The concept could also be extended to other kinds of disasters such as floods.

In any event, the implementation of the concept of functional adequacy during, and subsequent to, an earthquake is requiring new approaches in design for all components necessary for the operation of the building, new kinds of building code provisions, and multidisciplinary approaches to the overall design.

INUNDATION MAPS OF AREAS DOWNSTREAM FROM DAMS

For many years, a state agency has concerned itself with the safety of dams, including seismic safety. Its safety requirements were guided by the state-of-the-art of dam design and construction which, of course, changes with time. In general, this agency has performed excellently.

However, the 1971 San Fernando earthquake showed that the state-of-the-art of the design and construction of dams, just as that for buildings, was not perfect as evidenced by the near catastrophic failure of the Lower San Fernando Dam. (This dam had received a conditional approval of the state agency prior to the earthquake.) As a partial result, subsequent legislation required certain dam owners to file inundation maps with specified agencies that are concerned with dam safety and disaster preparedness.

The foregoing was a change in public policy in that dams are no longer considered to be "perfectly" safe by the public even though checked by state agencies. The preparation of inundation maps clearly indicates a hazard which is presumably sufficiently small to be considered as an acceptable risk for downstream public usage. Conceivably, in time, public pressure could require secondary or back-up construction features for downstream vital facilities. Some precedent already exists for this in the design of nuclear power reactors.

EARTHQUAKE GEOLOGICAL HAZARDS AND LAND USE

Increasing public concern has been given to construction in geologically hazardous areas. Earthquake geologic hazards are usually classified as active geologic faults, structurally poor ground areas (as marshlands), and potential landslide areas.

Problems related to structurally poor ground have received attention from the San Francisco Bay Conservation and Development Commission (BCDC) since the Commission appointed on February 16, 1968, what is now known as an Engineering Criteria Review Board. This Board, which includes an architect, examines the design criteria for proposed projects on San Francisco Bay margins where soils are normally of structurally poor types, often classified as "Bay Mud." The Board's policies are intended to insure such additional safety measures as may be necessary to adequately compensate for any increased risk, including seismic risk, on the poor ground areas. As a result, a project generally is buildable, but it may be shelved due to increased construction costs needed to meet the special design criteria. From a public policy standpoint, it should be understood that the designation of areas of structurally poor ("hazardous") soil does not prohibit construction on them, provided that the design has appropriately compensated for the unfavorable conditions.

Earthquake active faults, such as the San Andreas, Newport-Inglewood, and Hayward, have received considerable attention in the press. These faults, among others, certainly pose special problems for buildings located on them as well as for facilities which must cross them such as highways and water and gas mains. Two post-1971 bills warrant special attention. One bill, directed towards city planning efforts, specifies that a seismic safety element must be included in city and county general plans and, therefore, it becomes necessary to study and report on geologic hazards, including active faults. This legislation is being currently interpreted to include non-geologic hazards such as damage to buildings throughout a city and to earthquake disaster response.

The second piece of enacted legislation is , in effect, a state-local partnership with respect to earthquake active faults. The following are excerpts from the legislation which indicates the direction of public policy (from Section 660 of the Public Resources Code):

> .....To assist cities and counties in their planning, zoning,

and building regulation functions, the State Geologist shall delineate, by December 31, 1973, appropriately wide zones to encompass all potentially and recently active traces of the San Andreas, Calaveras, Hayward, and San Jacinto faults, and such other faults, or segments, thereof, as he deems sufficiently active.....

.....Such special studies zones shall ordinarily be one-quarter mile or less in width.....

.....Within the special studies zones....., the site of every proposed new real estate development or structure for human occupancy shall be approved by the city or county..... in accordance with policies and criteria established by the State Mining and Geology Board and findings of the State Geologist.....

This bill, in effect, gives local jurisdictions access to certain kinds of technical competencies which most of them do not have, or only have to a limited degree. This partnership between state and local government will be interesting to watch since, if successful, it could be a vehicle for other efforts.

MAJOR CURRENT POLICY ISSUES

There are a number of public policy issues which are receiving substantial current attention. Two of these warrant special mention at this time.

First, the greatest single seismic hazard in many communities is the collapse of older hazard structures. The vast majority of these collapse hazard structures have unreinforced brick bearing walls, have weak sand-lime mortar, and usually were built prior to 1933. Direct costs of demolition or rehabilitation are only one part of a very complex problem. Demolition without replacement reduces the tax base, often displaces the poor and elderly, and normally raises cultural issues in historic areas. Rehabilitation often has a negative benefit-cost; for example, taxes may increase due to seismic construction improvements, but these improvements in themselves may not warrant a rent increase to cover construction costs and increased taxes in the competitive marketplace. The complexity of the problem is primarily responsible for the reluctance of government to begin abatement of hazardous buildings.

Second, the possibilities are increasing that an earthquake prediction system will become feasible before many years pass. A host of public policy issues are presently developing in this subject area.

THE JOHN A. BLUME EARTHQUAKE ENGINEERING CENTER

James M. Gere

CONTENTS

DESCRIPTION

The participants of the Summer Seismic Institute were given a presentation/demonstration of the John A. Blume Earthquake Engineering Center.

Stanford's modern and well-equipped laboratory for testing and experimentation in structural engineering and geotechnical engineering is housed in the John A. Blume Earthquake Engineering Center, located on the Stanford University campus and part of the Department of Civil Engineering.

The laboratory contains a wide variety of mechnaical and electronic equipment, including a shake table, MTS static and dynamic testing system, Fourier analyzer and laser interferometer system, static test bed, crash sled, and a complete data processing and computer system to handle earthquake record digitizing as well as data analysis.

The shake table is 5 ft. by 5 ft. in plan and can be used as an undirectional seismic simulator. The table is activated by a hydraulically-driven and electronically-controlled ram that can simulate any desired type of input motion, from simple harmonic to purely random motion. The computer located within the Center can control the shake table and can reproduce the motion of any past earthquake record. Various velocity, displacement and acceleration transducers can be used to take the data from the model at the rate of 45,000 data points per second on sixteen different channels.

The MTS static and dynamic test system consists of three testing units, each capable of developing tensile and compressive loads statically or dynamically. Again, any desired dynamic load can be simulated. The equipment is very versatile with respect to the types of loads, the rates of load applications, and the nature of specimens being tested.

The Fourier analyzer is a special-purpose computer that determines the Fourier spectrum of any input signal. Because it is portable it can be taken to a field site for on-the-spot determinations of natural frequencies of vibration and amounts of damping in structures. Accompanying it are a laser interferometer and various accelerometers that are used to record the dynamic response of the structure (either under ambient conditions or when being shaken).

The data processing equipment is located in the main computer room of the Center. The system includes a central 32K memory computer with 2.5 million bytes disc, a magnetic tape unit, sixteen channels of analog to digital conversion, four channels of digital to analog conversion, a graphic unit for automatic plotting of results, a hard copy unit which gives 8-1/2' x 11" plotted hard copies of results including tables and graphs, a CRT terminal for control of the system, a buffer 8K memory computer to handle the digitizing table, and a digitizer. The system also has a high speed line

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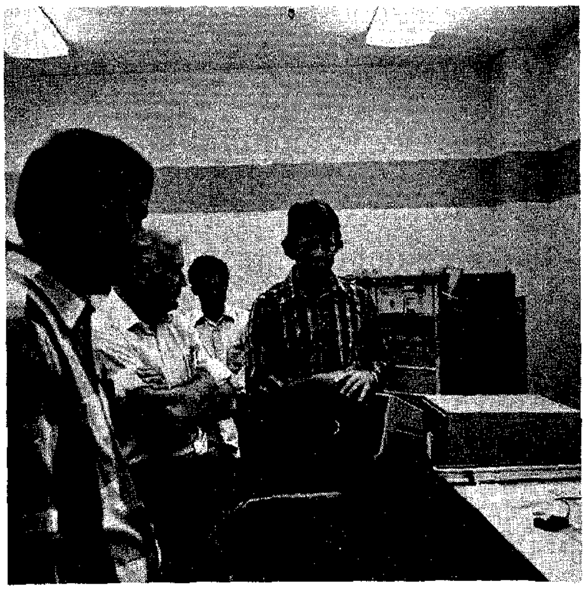
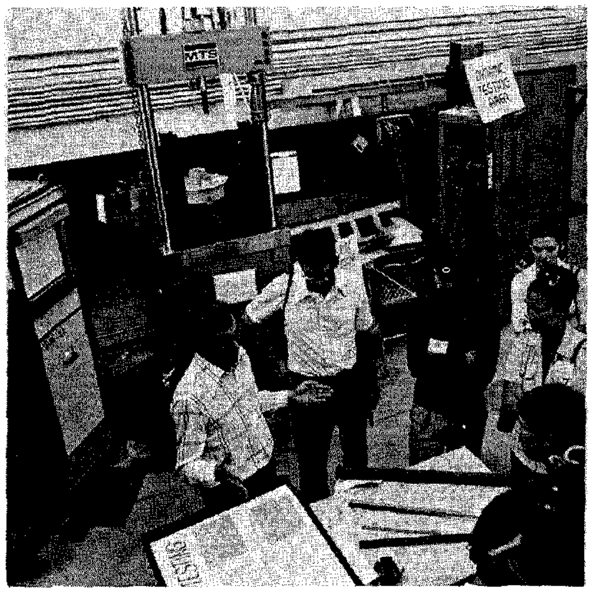
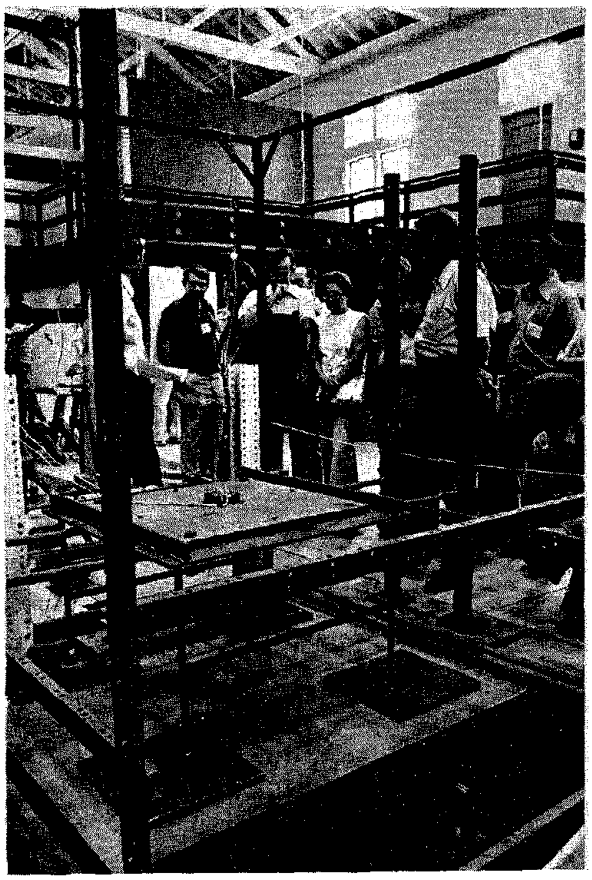
printer and a large Calcomp plotter. The system is designed to handle any problems associated with digitizing as well as analysis of earthquake data. The stystem described above is the latest electronic data handling system that is available.



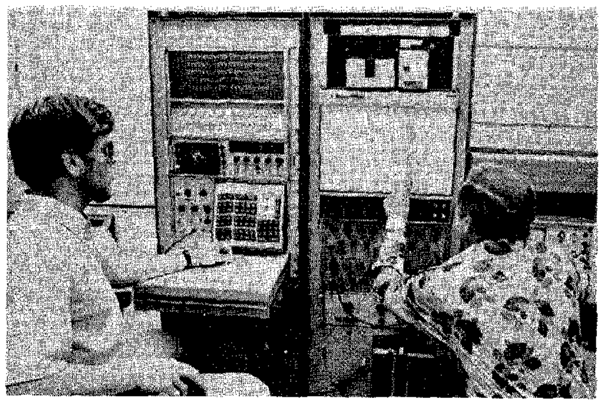
DATA PROCESSING EQUIPMENT



MTS TEST SYSTEM



THE SHAKE TABLE



FOURIER ANALYZER

LIQUEFACTION DEMONSTRATION

NATIONAL SCIENCE FOUNDATION EARTHQUAKE ENGINEERING PROGRAM

John B. Scalzi

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NATIONAL SCIENCE FOUNDATION EARTHQUAKE ENGINEERING PROGRAM

Earthquakes pose a severe threat to life and property for the entire country. The Earthquake Engineering Program at the National Science Foundation is organizad to support research to mitigate the effects of disasters. The paper discusses the general areas of interest to be siting, design and policy.

Earthquakes are one of nature's severest geophysical hazards. Portions of 39 States with 70 million residents are in areas subject to major or moderate seismic risk. Although damaging earthquakes are relatively rare at a site, they can have a continuing impact on the community through increased investment on capital structures, restricted land use, and condemnation of hazardous structures to achieve adequate earthquake performance, and the maintenance of preparedness programs and payment of insurance premiums. The occurrence of an earthquake impacts the community through the direct loss of life, injury and property damage, losses and costs incurred in the operation of disaster relief and rehabilitation programs, loss of income due to business disruption, personal injury, and disaster-caused psychological problems. Under the aegis of the President's Science Advisor, a report on Earthquake Prediction and Hazard Mitigation was submitted to the President in September 1976. It presents options for future development of the National Science Foundation and United States Geological Survey research programs and its Option B is the basis for the strengthening of the program subelement. The goal of the joint NSF-USCG earthquake prediction and hazard mitigation activities is to reduce casualties, damage, and social and economic disruption from earthquakes.

The program is directed toward the development of research data in all the disciplines related to man-made structures and related community activities. A modified re-statement of the program description from the 1978 NSF budget as submitted to Congress may be the most direct method to explain the intent and scope of the earthquake engineering program.

The social, economic, and political actions which can be taken to attain the desired survival are based on technological capabilities that require development through research. The primary objectives of this research are:

1. Earthquake Prediction - Develop the capability to predict the time, place, magnitude and effects of earthquakes so that more effective preparedness actions can be undertaken.

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2. Earthquake Modification and Control - Develop techniques that allow the control or alteration of seismic phenomena.

3. Land Use - Develop procedures for assessing seismic risk and evaluating earthquake hazards so that appropriate construction and land use plans can be implemented.

4. Design Improvement - Develop improved, economically feasible design and construction methods for building earthquake resistant structures of all types and for upgrading existing structures.

5. Social and Behavioral Response - Develop an understanding of the factors that influence public utilization of earthquake mitigation methods.

Responsibility for fundamental earthquake studies to help meet the goal of this program are with the Geophysics program subelement of NSF and USGS. Earthquake prediction, induced seismicity and hazards assessment are the responsibility of USGS, and earthquake engineering and research for utilization are the responsibility of NSF/RANN. These agency programs are closely coordinated through formal and informal mechanisms to achieve the objectives set forth in the report to the President.

The RANN Earthquake Engineering subelement is organized and presented in three major categories: Siting, Design and Policy.

The siting category includes topics of ground motion and their resulting effect on the earth's surface. Earthquake damage results from the energy released by the earthquake being transmitted through rock and soil to the site where a facility is located. In some cases an earthquake may trigger secondary geophysical hazards, such as tsunamis, land slides, or flood waves from ruptured dams, that can have devastating impacts. The siting research area seeks to determine the nature of the potentially damaging earthquake hazards at particular sites so that structures may be adequately designed and social and economic policies may be appropriately developed. The specific objectives of this research area are to:

1. Improve methods to characterize the nature of the input motions and corresponding response of simple structural systems for use in engineering analysis, planning and design.

2. Obtain a comprehensive data base on the nature of earthquake motions at typical sites and in representative structures.

3. Devise in-situ and laboratory methods to determine the dynamic properties of soils and analytic procedures, including the potential for failure of slopes, embankments and foundations.

4. Identify procedures for integrating information on geophysical hazards into land use planning and siting procedures.

Fundamental to the process of designing a facility or assessing its vulnerability is an accurate characterization of the earthquake-generated loads that it must withstand. Current knowledge of the strong ground motion that arises from damaging earthquakes is limited to a few events, such as the San Fernando Earthquake of 1971, and then only to widely spaced ground measurements. One essential step in developing knowledge on strong ground motion is the establishment of special three-dimensional instrument arrays to measure motion of nearby points on the ground surface and at different depths. Such data will provide the only adequate basis for the selection among alternative theoretical models of the manner by which ground motion changes with distance and with types of soils and rocks.

Basic principles of land planning dictate that systems should not be located where soil failure or instability such as liquefaction or landsliding is likely to occur. Many times, however, systems such as wharfs, bridge approaches, and highways must be or have been located at sites where soil failure is likely. In other cases, buildings already exist where such potential is now recognized. Research will improve methods to predict possible soil failure or alleviate its consequences.

Earthquake forces are transmitted to a structure through its foundation's dynamic interaction with the supporting and surrounding soils. Current techniques for determining this interaction are primarily linear and are limited to elastic situations, while observed response of soils and soil-foundation systems during earthquakes are mostly in the non-linear range. Research on the non-linear dynamic behavior of soils and soil-structure interaction will not only provide a basis for structural design analysis, but will also provide a rational basis for performing microzonation studies of large regions. Microzonation, which takes into account seismicity, geology and local soil anomalies, could provide a great improvement in engineering and management decisions concerning land use planning, siting of structures and cost optimization of earthquake protection for systems and networks of large, complex industrial facilities.

For the majority of design cases, particularly the design of simple, non-critical structures, the general level of ground motion in frequently occurring events and the maximum probable motion from infrequently occurring events are sufficient. Special emphasis is placed on devising simple ground motion techniques appropriate for application when complex design or analysis of individual structures is not appropriate or economically realistic.

The design category involves the process of design, analysis and construction are central to the achievement of safe structures and systems. In turn, these processes depend on the formulation, testing, validation and presentation of appropriate conceptual and mathematical representations of their characteristics. These models must represent the capacity of the structures and systems at various levels of motion which occur in potentially damaging eartquakes. They must include multi-dimensional, nonlinear, and inelastic characteristics. At present, design procedures are largely based on linear, elastic, planer models.

The specific objectives of this research area are to:

1. Improve analytical procedures for characterizing the earthquake response of structures and structural elements based on both analytical and experimental studies.

2. Devise analytical methods to evaluate the earthquake response of special types of structures such as dams, critical facilities, bridges and other extended structures and of interconnected structures and systems such as pipelines, transmission lines, and transportation systems.

3. Obtain information for engineering analysis and design from observations of damage or lack of damage following earthquakes that support the development of improved engineering practices and construction techniques.

4. Identify economically feasible design and construction methods for building earthquake resistant structures and facilities.

5. Develop methods to evaluate the hazard potential of existing structures and investigate innovative methods for improving their performance.

To obtain the data required to evaluate modeling procedures will require using instrumentation of actual structures in seismically active areas as well as laboratory studies of the ultimate capacity of elements and substructures. Since the analysis of structures and systems at damaging motion levels involves nonlinear and inelastic properties, such analyses are necessarily complex. In the design of large or critical structures and systems, it is necessary to devise reliable methods that sequentially increase in complexity as the design process proceeds. The economics of the design and construction of smaller, noncritical structures does not permit extensive or complex design or analysis of individual structures, in spite of the fact that they comprise the largest aggregate value of structures likely to be damaged. Research has been initiated or substantially expanded to determine the nonlinear, multi-dimensional response of structures and to develop improved guidelines to decrease the damage potential of individual non-engineered structures. A large scale static test facility may be designed to complement existing dynamic testing facilities. There are plans to enter into cooperative research programs with Japan to utilize their large shake table which is now under construction.

The majority of existing buildings have little earthquake resistance, including many buildings in high risk areas of the West. This occurs because earthquakes were not considered in their construction; the structural resistance provided against other dynamic loads, e.g., wind, is insufficient; or the earthquake risk was underestimated. Previous initiatives to upgrade hazardous structures have been limited by high cost. Costs reduced by several factors still seem too high to warrant widespread upgrading of structures when one considers the average risk and realistic economic discount factors. However, the emerging potential for earthquake prediction could substantially alter this economic environment to one in which decisions to upgrade hazardous structures may be made by stimulating the investment of substantially larger amounts to obtain improved seismic performance in selected areas. For this reason, research on upgrading and reinforcing existing hazardous structures is greatly expanded. Particular attention is given to Western masonry structures and to other potentially hazardous building types prevalent in the Eastern and mid-Western United States. Specific research areas include:

1. Investigating the seismic response and design features of existing buildings, with emphasis on reinforced and unreinforced masonry buildings;

2. Improving structural reinforcement design and construction procedures to upgrade seismic performance of existing structures;

3. Identify policy alternatives to reduce the impact of earthquake predictions and occurrences, with emphasis on land use regulations, building codes, condemnation procedures, and indemnification.

Earthquakes and other dynamic hazards, including extreme winds, accidents and explosions, expansive soils, large-scale land subsidence, floods and storm surge have similarities both in the nature of the loads applied to structures and in the design and analysis procedures used to withstand these loads. Studies have been initiated to determine similarities in these loadings and to develop research and application initiative to adapt methods developed in earthquake engineering to the mitigation of other dynamic hazards. Specific initiatives to be undertaken are:

1. Investigate the adequacy of buildings designed to withstand other geophysical hazards to provide simultaneous earthquake resistance, and vice versa.

2. Develop new and improved understanding of the dynamic and long-term behavior of buildings to dynamic hazards.

3. Integrate earthquake developed methods of analysis and design procedures and criteria with other dynamic load sources in forms suitable for professional design use and regulatory adoption.

Changes in building codes, standards and land-use regulations are important in mitigating earthquake hazards. Significant progress has been made in a previous project in which a model "Recommended Comprehensive Seismic Design Provisions for Buildings" was prepared. Future efforts will be aimed at the implementation of these recommended design provisions and also on providing a sound technical base for the improvement of the ANSI-A58 Lateral Load Standard. These efforts will require a strong interaction among researchers, professional designers and public officials.

The policy category will facilitate the utilization of research findings developed in the NSF and USGS research programs on earthquake hazards by private citizens and organizations, local communities, and State and Federal agencies. This activity will require increased research on such social adjustments to earthquakes as preparedness and relief and rehabilitation, as well as new research initiatives to identify factors related to the actual adoption of known social and technological solutions to disaster-generated problems.

The specific objectives of this research area are to:

1. Increase the base of knowledge on alternative social adjustments to earthquakes.

2. Identify the social, economic, political, legal and related factors which facilitate or hinder the adoption of both social and technological solutions to earthquake hazards.

3. Facilitate the beneficial utilization of earthquake hazard mitigation measures by devising effective techniques for disseminating information to the public and decision-makers at the local, State and National levels.

4. Investigate measures which will reduce possible negative social, economic, and political consequences of earthquake predictions and warnings.

Three reports form the basis for the substantial strengthening of this research area: a University of Colorado report, Assessment of Research on Natural Hazards, the report to the President entitled, Earthquake Prediction and Hazard Mitigation, and the National Academy of Sciences' report on Earthquake Prediction and Public Policy.

Earthquake prediction may have the potential for saving countless lives and reducing social disruption caused by earthquakes. It offers the possibility of long lead times during which threatened communities can make vital preparations. A project on the possible social, economic, and political consequences of earthquake prediction indicates that a credible prediction is likely to be followed on the one hand by significant reductions in deaths, injuries, and property losses, while on the other hand creating major economic disruptions. New initiatives are planned to study the social and economic consequences of future earthquake predictions with special attention given to possible problems which might be averted through advance planning, such as unemployment, business failure, and the disproportionate sharing of losses by the old and poor. To complement the expanded research on earthquake prediction, this research area will increase research on the social impacts of prediction, including its impact on real estate values and public attitudes toward it.

Dissemination of research results is vital in any effort to increase the capability of both public and private officials to implement earthquake and other hazard mitigation measures. There is a need for knowledge on the most effective ways to disseminate information to relevant groups and organizations before, during, and following earthquakes and other disasters. More effective means must be found to increase the interaction between the research and user communities so that important findings on building construction, emergency preparedness, relief and rehabilitation, insurance, and emergency communications become known to individuals, and to public and private agencies with hazard mitigation capabilities and responsibilities. An initial effort to develop techniques for disseminating research findings on earthquakes was made in 1971 with the creation of the National Information Service in Earthquake Engineering which collects, collates and disseminates technical information on earthquake engineering. In 1976, the dissemination of socio-economic and policy information was started with the creation of the Natural Hazards Research Applications Information Center. Research on the utilization process will concentrate on evaluation of technology transfer mechanisms.

A recently funded study on the constraints to the adoption of hazard insurance in earthquake and flood susceptible areas indicates that inhabitants of a threatened area may fail to adopt effective protective measures if they are insufficiently aware of the dimensions of the hazard and ways of dealing with it. A major initiative is to be launched to study the popular perceptions and understandings of earthquakes in susceptible regions of the Nation and how they can be made more realistic. Findings from this research should provide answers to the kinds of public information measures that should be performed by public officials in earthquake prone areas who have the responsibility of encouraging citizens to take actions which will protect their lives and property.

Specific initiatives to be undertaken are:

1. Comparative studies of earthquake planning at the local and State levels;

2. Investigate the problems in the mobilization of construction resources, including manpower and materials, following earthquakes and other disasters;

3. Socio-economic monitoring of communities following earthquake predictions and near predictions;

4. Study cost-benefit methods of analysis to provide public and private officials a basis for choosing among possible earthquake mitigation actions;

5. Assess the impact of existing local, State and Federal legislation on earthquake mitigation and the need for new regulations.

The earthquake program is a broad one, of necessity, in order to research all topics required to develop an informational and data base for decisionmakers to act in considering options for disaster mitigation and emergency preparedness. The researchers are predominantly from the academic institutions but non-profit and profit organizations are eligible to participate in the program. The important aspect is the expertise to develop a research topic to a meaningful and successful conclusion. Only by this method can we develop the information to design buildings and promulgate policies to survive severe hazards such as an earthquake.

SECTION 2

STRATEGIES

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The following section includes certain strategies that can be used to assist in the incorporation of seismic design into schools of architecture.

Certain perceived barriers to this incorporation are briefly discussed along with certain strategies that could be used to overcome these barriers and promote the utilization of seismic design in architectural schools. These recommendations were discussed and developed by the architectural faculty participants at the seismic institute.

A matrix displaying these barriers and strategies is included to visually present the wide range of issues. The matrix shows the range of strategies that attack the perceived barriers; most would attack more than one barrier. The long- and short-term symbols identify those strategies that would stand a good chance of having a short-term (immediate) or long-term impact on the barrier once the strategies are implemented. This matrix thus shows those strategies that once implemented would both attack and have an immediate or long-term impact of certain barriers. The barriers to implementing the strategies are not shown or discussed since these would change between school and region. Thus the final decision as to which strategy or strategies would be most effective would lie in determining the probable barriers to implementing the specific strategy at each particular school.

A. INFORMATION OVERLOAD

There may be a reluctance on the part of architectural faculty to integrate additional material into their already full courses. Design faculty may be unreceptive to placing another design concern into their studio, especially one they may perceive as an extremely technical issue. Some schools and courses are presently experiencing an information overload because of new concerns of environmental design, energy consciousness, designing for the handicapped, building security, etc. The faculty who are instrumental in determining the degree of importance given to an emerging design concern in their course may perceive seismic design as an inappropriate concern for design studios and more relevant to technical courses.

1. Seismic design, although having structural solutions, is in itself a design problem needing the expertise of all design professions in its solutions. The architect, as the design team leader, is instrumental in determining the building's site location, shape, form, configuration, basic structural system, materials, architectural systems/components, and basic mechanical/ electrical systems. These decisions will determine the seismic performance of the building and the cost of designing the selected systems to be earthquake resistant. A documentation of the results of certain architectural design decisions during earthquakes can

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illustrate the critical importance of the architects' knowledge and appreciation of seismic design.

2. An understanding of the interrelationships of seismic design and other design concerns presently presented in architectural schools can help negate the perception that seismic design is an isolated issue. An identification of the reinforcing nature and the conflicting nature of seismic design and these other design concerns would promote the applicability of incorporating seismic design with other relevant design information and concerns.

3. Seismic design can be emphasized as a logical design process. There is a definite problem to be addressed and a large portion of the problem can be solved in schematic design. Seismic design can become a form generator solving a problem that effects the life safety of the public and thousands of dollars in building loss or repair. Because of the logical nature of seismic design, the final design may in fact assist in the solution of other important design problems.

4. Seismic design can gradually be brought into architectural studios and courses as an understanding of the problem develops. Individual faculty members who are knowledgeable in seismic design could, through studio critiques, begin to build an awareness in students as well as other faculty members.

B. RELUCTANCE TO CHANGE CURRICULA

Because of several factors such as the lead time involved and the administrative process, some architectural administrations and faculty may be reluctant to change curricula to incorporate seismic design.

5. The effort to incorporate seismic design into schools can begin gradually, thus encouraging the participation of all faculty in determing the direction of the later formal changes, if any are needed. Faculty can be encouraged to incorporate applicable aspects of seismic design into their existing courses without threatening the autonomy or diversity of either the faculty members or their courses.

6. Because seismic design and even life safety design are lacking in many schools of architecture, there exists the distinct potential for professors and schools to develop an area of professional reputation in seismic/ life safety design.

C. PERCEIVED LACK OF IMPORTANCE

There may be a reluctance for faculty to incorporate seismic design into schools of architecture because of a perceived lack of importance of seismic design and its relevance to the regional location of the school. This false perception can be translated into a lack of awareness or inertia on the part of the faculty.

7. Traveling exhibits (inexpensive, easy to set up) can be used at schools to build an awareness of the importance of seismic and life safety design.

8. Workshops/conferences can promote the regional risk to the faculty participants.

9. Seismic design can be included in the larger concern of life safety design to increase its perceived importance. This promotion of life safety design may increase the concern and involvement of a larger number of faculty members and students.

10. It can be emphasized that architectural schools teach future architects who may practice anywhere in the country or the world. These future professionals will have to pass licensing exams that include seismic design. In addition, they will deal with life safety hazards that are not always expressed in codes.

D. LACK OF KNOWLEDGE IN SEISMIC DESIGN

Because of a perceived lack of responsive data and information on seismic design, architectural faculty may be reluctant to teach in an area in which they might feel unknowledgeable.

11. Traveling seminars/lectures can be given at schools to introduce seismic design to faculty.

12. Longer conferences/workshops/institutes can be given for architectural faculty to increase their knowledge of seismic design.

13. Intensive continuing education programs can be used to bring academic and practicing professionals together in the area of seismic design.

E. PERCEPTION AS TECHNICAL SUBJECT

Faculty may see a potential conflict in incorporating what is perceived as an extremely technical concern into the architectural design studio. Seismic design when perceived as a technical issue may be delegated to those courses and faculty outside the studio setting.

14. It can be emphasized that a major portion of seismic design can be approached in the analysis and schematic design phases.

15. Seismic design can be introduced as the solution of an environmental hazard problem rather than limited to a structural design problem.

16. Again an emphasis on the life safety issues of seismic design may promote an awareness of non-technical solutions involved in seismic design.

F. INTERDISCIPLINARY CONSTRAINTS

There may be a reluctance on the part of architectural faculty to promote the incorporation of design concerns that cross several traditional disciplines or interests.

17. Interdisciplinary exchanges of information, expertise, and experience can be encouraged through the use of multidisciplinary research teams, faculty exchange programs and school exchange programs.

18. The use of certain architectural faculty and/or engineering faculty as consultants in design studios can be encouraged.

19. Joint projects or programs with other departments can be developed in seismic/life safety design.

G. LACK OF STUDENT INTEREST

Lack of student awareness and interest may increase the reluctance of faculty to incorporate seismic design into their courses or curriculum. Architectural students may see earthquake design as a structural engineering exercise of limited focus and usefulness to the architect. Seismic design solutions may be seen only as a mathematical procedure which should be left to the engineer.

20. Various aspects of seismic design can be promoted as thesis topics for architectural students. This could increase an awareness of the entire school since thesis presentations are often attended by and exposed to a large portion of the students and faculty.

21. Seismic design/life safety design competitions can be held for architectural students throughout the country. This could increase the awareness of seismic design concerns as well as promote its importance through the publicity involved in the competition.

22. Student publications and media can be used to involve the student body in promoting seismic design.

23. Theme weeks, prevalent in architectural schools, could be used to promote seismic/life safety design. Student committees could select certain experts to lecture and give presentations on aspects of life safety design. The involvement of students in such a "life safety week" could promote an awareness of such issues and concerns in the schools.

H. LACK OF INTEREST OF PROFESSION

Noting the relative non-existence of the architectural profession's past involvement in earthquake research, architectural faculty may perceive this lack of involvement as a lack of the need for their expertise in the solution of the problem. Because of the emerging interest and involvement of practicing architects in seismic research, there has not yet been a chance for the translation into schools of architecture. Therefore, there will probably be a parallel building of concern in both the practicing and academic communities, each feeding the other. For this reason, the involvement of practicing architects and firms must be promoted to give a sense of importance and relevance of seismic design to the profession.

24. Involvement of architects as members of post-disaster teams can be promoted to assist in providing examples of architectural involvement and concern.

25. Examples of good seismic design by architects can be identified and documented to give a sense of recognition of the importance of seismic design issues and concerns.

26. Case studies of building performance during earthquakes can be documented to show the good and poor effects of certain architectural design decisions. Case studies need not be confined to buildings, but can also include documentation of the performance of a community to illustrate the consequences of urban design and planning decisions.

27. A professional committee or task force on life safety or natural hazards can be created to emphasize the importance of, and give a national focus to, these issues.

28. The design leadership role of the architect can be emphasized to draw attention to the architects' responsibility to recognize the importance of their part in determining the successful or poor performance of a building during an earthquake. Seismic design taught in schools of architecture can thus dramatically add to a

fuller awareness and education of future architects.

I. LACK OF CURRICULUM DEVELOPMENT

Architectural faculty may be reluctant to incorporate seismic design into their courses because of the lack of development of a suitable curriculum. This lack of knowledge about which aspects of seismic design are appropriate to which architectural courses can be an effective barrier to the planned incorporation of seismic design into architectural curricula.

29. Curriculum development programs can be promoted to identify which seismic design issues are most efficiently and effectively incorporated into which architectural courses. Although the diversity of architectural schools is well known, such a cross matching of issues and courses, with the development of appropriate teaching aids, would benefit all schools in planning any curriculum changes which would incorporate seismic design concerns. Architectural courses that might include seismic or life safety issues include:

    Introduction to Architecture
    Design Studios
    Structures
    Environmental Systems
    Construction Methods
    Specifications
    Professional Practice
    Interiors
    Materials
    Urban Design
    Site Planning
    Man-Environment Relations

30. The documentation of the failures and/or successes of attempts by architectural faculty to incorporate seismic design into their courses or schools would assist other faculty and schools in planning for the implementation of seismic design in curricula.

J. LACK OF USEABLE INFORMATION

A major barrier to the incorporation of seismic design into schools of architecture is the lack of an information base that is both responsive and useful to architectural faculty and schools.

31. Long term research projects can be sponsored to translate the existing earthquake research data into useable and responsive information.

32. Seismic research can be promoted in schools of architecture.

33. A central repository of seismic/life safety design information can be organized. Such a repository would contain slides, films, reports, etc. that would be available to interested faculty.

34. Seismic design text books can be produced for use in schools. Workbooks can be developed for use during the design problem-solving process.

35. Because of the teaching methods used in architectural education, maximum use can be made of a multi-media approach. Slides, movies, models, drawings, etc. can be developed that are responsive to the needs of architectural professors and their students.

36. Computer programs can be developed to be used as a tool in teaching seismic design.

37. Annotated bibliographies of relevant and appropriate documents and non-print materials can be developed as a tool for architectural faculty. In addition, a list of contacts and resource persons could be maintained.

STRATEGIES FOR INCORPORATING SEISMIC

● SHORT TERM

• LONG TERM

BARRIERS \ STRATEGIES	1 DOCUMENTATION OF SEISMIC RESULTS OF DESIGN DECISIONS	2 IDENTIFICATION OF SEISMIC DESIGN CONFLICTS	3 PROMOTE SEISMIC DESIGN AS LOGICAL DESIGN PROCESS	4 SEISMIC CRITIQUES IN DESIGN STUDIOS	5 GRADUAL FACULTY PARTICIPATION	6 REPUTATION DEVELOPMENT OF SCHOOL OR FACULTY	7 TRAVELING EXHIBITS	8 WORKSHOPS/CONFERENCES TO PROMOTE REGIONAL RISK	9 PROMOTE IN LIFE SAFETY CONTEXT	10 EMPHASIZE PROFESSIONAL NEED (LICENSING EXAMS)	11 TRAVELING SEMINARS AND LECTURES	12 EDUCATIONAL INSTITUTES AND WORKSHOPS	13 PROMOTE CONTINUING EDUCATION	14 EMPHASIZE SEISMIC CONCEPTS IN EARLY DESIGN PHASES	15 PROMOTE IN ENVIRONMENTAL HAZARD CONTEXT	16 EMPHASIZE NON-TECHNICAL SOLUTION
A INFORMATION OVERLOAD	•	●	•	•	•											
B RELUCTANCE TO CHANGE CURRICULA				•	•	•										
C PERCEIVED LACK OF IMPORTANCE	•		•	•		•	●	●	•	•	●	●	●			
D LACK OF KNOWLEDGE IN SEISMIC DESIGN				•			●	●			●	●	•			
E PERCEPTION AS TECHNICAL SUBJECT		●	•	•			●	●	•		●	●	●	●	●	•
F INTERDISCIPLINARY CONSTRAINTS				•												
G LACK OF STUDENT INTEREST						•	●		•	●	●			●		●
H LACK OF INTEREST IN PROFESSION	●									•			•			
I LACK OF CURRICULUM DEVELOPMENT																
J LACK OF USEABLE INFORMATION	•	•														

DESIGN INTO SCHOOLS OF ARCHITECTURE

●			●	●		●				INTERDISCIPLINARY PROGRAMS AND EXCHANGES	17
				⬤		●			●	USE OF STUDIO CONSULTANTS	18
				●			⬤			JOINT PROGRAMS BETWEEN SCHOOLS	19
●			⬤				●			PROMOTE SEISMIC DESIGN AS THESIS TOPICS	20
●			●	⬤	⬤		⬤			SEISMIC STUDENT COMPETITIONS	21
			⬤		●		●			PROMOTE SEISMIC DESIGN IN STUDENT MEDIA	22
			⬤	●	⬤	⬤	⬤			SEISMIC/LIFE SAFETY THEME WEEKS	23
●		●		●			⬤			POST DISASTER TEAMS	24
		●	●		●		●			RECOGNITION OF GOOD SEISMIC DESIGN	25
⬤		●			●					DOCUMENT CASE STUDIES OF SEISMIC PERFORMANCE	26
		⬤					⬤			AIA COMMITTEE/TASK FORCE	27
●		●	●		⬤		⬤			EMPHASIZE SEISMIC IMPLICATIONS OF DESIGN DECISIONS	28
	●				⬤			⬤	●	CURRICULUM DEVELOPMENT PROGRAMS	29
	●							●		DOCUMENTATION OF CURRICULUM CHANGES	30
●					●	●				INFORMATION AND DATA TRANSLATION	31
●			●	●	⬤	●	●			PROMOTE SEISMIC RESEARCH IN SCHOOLS	32
●										CENTRAL AUDIO-VISUAL REPOSITORY	33
●					●	●	●	●		DEVELOP SEISMIC TEXTBOOKS AND DESIGN WORKBOOKS	34
⬤			●						●	UTILIZE MULTI-MEDIA APPROACH	35
⬤	●								●	COMPUTER LEARNING PROGRAMS	36
⬤						⬤				ANNOTATED RESOURCE BIBLIOGRAPHIES	37

SECTION 3

RESOURCES

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RESOURCES

The following section presents an annotated bibliography of seismic design resources that can be used by architectural faculty and students. The reports/books list identifies those publications that are felt to be most responsive to, and usable by, the architectural profession. Brief descriptions and relevant information are given. The movies/slides list describes available earthquake movies and slide sets. The abstracts/information services list shows publications that identify earthquake research projects and publications as well as available information services. The periodicals list identifies available earthquake newsletters and periodicals.

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REPORTS/BOOKS

AIA Research Corporation. Architects and Earthquakes. Government Printing Office: Washington D.C. 1977. (GPO 038-000-00331-3, $2.20).

Basic introductory text to seismic design pre-prepared to build an awareness and assist in the basic understanding of earthquakes and their effect on buildings. The report emphasizes how architectural design decisions can affect the seismic performance of buildings. Extensive illustrations. (94 pages)

AIA Research Corporation. Architects and Earthquakes: Research Needs. AIA/RC: Washington, D.C. 1976. (NTIS).

This report documents the proceedings and papers of the Seismic Safety Research Workshop held in 1976 to develop areas of future research that are responsive to the architect's needs in the mitigation of earthquake damage and loss. (247 pages)

Algermissen, S. T. et al. A Study of Earthquake Losses in the San Francisco Bay Area. Office of Emergency Preparedness: Washington, D.C. 1972.

The purpose of this report was to provide essential data for effective pre-disaster planning for major damaging earthquakes that might affect the San Francisco Metropolitan Area. (220 pages)

Algermissen, S. T. et al. A Study of Earthquake Losses in the Los Angeles, California Area. Federal Disaster Assistance Administration: Washington, D.C. 1973. (GPO 0319-00026).

The purpose of this report was to provide essential data for effective pre-disaster planning for major damaging earthquakes that might affect the Los Angeles Metropolitan Area. (331 pages)

American Iron and Steel Institute. Earthquakes. AISI: Washington, D.C. 1975. Contact: American Iron and Steel Institute, 1000 16th Street, N.W., Washington, D.C. 20036.

Reprint of four earthquake reports of the Morocco (1960), Yugoslavia (1963), Alaska (1964) and Venezuela (1967) earthquakes. The report investigates the seismic damage and destruction of various specific buildings. Extensive illustrations. (319 pages)

American Iron and Steel Institute. The Managua, Nicaragua Earthquake December 23, 1972. AISI: Washington, D.C. 1973. Contact: American Iron and Steel Institute, 1000 16th Street, N.W., Washington, D.C. 20036.

This report contains two papers discussing both the earthquake effects and damage to buildings and lifeline systems during the 1972 Managua earthquake. (54 pages)

Anonymous. Seismic Design For Buildings. Department of Defense: Washington, D.C. 1973. (GPO 0820-00457, $4.70).

Prepared to govern design of facilities for the U.S. Armed Forces in areas subject to seismic events. Methods and factors specified were selected to provide sound design against earthquakes at relatively low costs. (420 pages)

Architectural Institute of Japan. Design Essentials in Earthquake Resistant Buildings. Elsevier Publishers: New York. 1970.

Not reviewed.

Ayres, Robert S. Earthquake and Tsunami Hazards in the U.S.: A Research Assessment. University of Colorado: Boulder 1975. (Monograph NSF-RA-E-75-005) Contact: Institute of Behavior Science, University of Colorado, Boulder, Colorado 80302.

This report provides a basis for judging the probable social utility of allocation of funds and personnel of earthquake research. It also discusses and appraises seismic research needs and recommendations. (150 pages)

Bolt, Bruce A., et al. Geological Hazards. Springer-Verlag, Inc. New York 1977. (ISBN 0-387-90254-6, $19.80).

This book addresses the general audience in explaining the mechanisms and processes of hazardous geologic phenomena and suggesting what could be done to reduce the potential for disaster from earthquakes and other geological hazards. (328 pages)

Bresler, Boris et al. Developing Methodologies For Evaluating The Earthquake Safety of Existing Buildings. Earthquake Engineering Research Center: Berkeley 1977. (NTIS)

This report contains four papers written during an investigation of methods for evaluating the seismic safety of existing school buildings. (142 pages)

Calder, Nigel. The Restless Earth. Viking Press: New York 1973. (SBN 670-00391-3, $3.95). Contact: The Viking Press, 625 Madison Avenue, New York, New York 10022.

This book discusses to the general reader the theory of plate tectonics and connection of earthquakes, volcanoes and mountain ranges to this movement of plates on the earth's outer shell. Extensive illustrations. (152 pages)

Culver, Charles G. et al. Natural Hazards Evaluation of Existing Buildings. National Bureau of Standards: Washington, D.C. 1975. (GPO C13.29:2/61, $11.10).

A methodology is presented for the survey and evaluation of existing buildings to determine the risks to life safety under natural hazard conditions and estimate the amount of expected damage. Three independant sets of procedures for estimating damage are presented and illustrated. (958 pages)

Dowrick, D. J. Earthquake Resistant Design: A Manual for Engineers and Architects. John Wiley & Sons: New York 1977. (27.50). Contact: John Wiley & Sons, Inc. 605 Third Avenue, New York, New York 10016.

This book describes the major factors relating to the design of structures in any material in order to minimize damage from earthquakes. The major theme is the design process, following a logical design office sequence. (374 pages)

Earthquake Engineering Research Institute. Learning From Earthquakes. EERI: Oakland 1977. ($5.00). Contact: EERI, 424 - 40th Street, Oakland, California 94609.

The purpose of this planning and field guide is to help maximize the learning that can be gained from investigations following future destructive earthquakes. (200 pages)

Goers, Ralph W. A Methodology for Seismic Design and Construction of Single Family Dwellings. Department of Housing and Urban Development: Washington D.C. 1977. Contact: Division of Energy, Building Technology and Standards, Office of Policy Development and Research, U.S. Department of Housing and Urban Development, Washington, D.C. 20410.

This report develops seismic-resistive design and construction recommendations to reduce future probable earthquake damage and hazards for single-family residences.

Haas, J. Eugene et al. Reconstruction Following Disaster. The MIT Press: Cambridge 1977. Contact: The MIT Press, Massachusetts Institute of Technology, Cambridge, Massachusetts 02142.

The purpose of this report is to fill the gap in knowledge about how cities recover from disaster. Four case studies are discussed along with alternate scenarios and recommendations. (331 pages)

Halacy, D. S., Jr. Earthquakes: A Natural History. The Bobbs-Merrill Co., Inc.: New York 1974. ($7.95).

A very basic book that discusses in general terms the causes and effects of earthquakes. (162 pages)

Iacopi, Robert. Earthquake Country. Lane Books: Menlo Park 1973. (SBN 376-06142-1, $2.95). Contact: Lane Book Company, Menlo Park, California 94025.

A general discussion of how, why and where earthquakes strike in California. The book discusses and locates the major California faults. Extensive illustrations. (160 pages)

Jennings, Paul C. (ed.). Engineering Features of the San Fernando Earthquake: February 9, 1971. California Institute of Technology: Pasadena 1971. (EERL 71-02). Contact: Earthquake Engineering Research Laboratory, California Institute of Technology, Pasadena, California.

A collection of papers which discuss and study some of the more important and interesting engineering features of the 1971 San Fernando earthquake. Extensive illustrations. (512 pages)

Jephcott, D. K., Hudson, D. E. The Performance of Public School Plants During the San Fernando Earthquake. California Institute of Technology: Pasadena 1974. Contact: Earthquake Engineering Research Laboratory, California Institute of Technology, Pasadena, California.

A collection of case study investigations into the performance of public school buildings during the 1971 San Fernando earthquake. (606 pages)

Keightley, W. O. Destructive Earthquakes in Burdur and Bingöl, Turkey - May 1971. National Academy of Sciences: Washington, D.C. 1975. Contact: NAS, 2101 Constitution Avenue, Washington, D.C. 20418.

This report documents the extent of damage sustained in the 1971 Turkey earthquake. It offers examples of damage and recommendations to mitigate future damage. (82 pages)

Lew, H. S. Engineering Aspects of the 1971 San Fernando Earthquake: National Bureau of Standards: Washington, D.C. 1971. (GPO C13.29/40, $3.00).

This report is based primarily on the data gathered during an investigation of the 1971 San Fernando earthquake. Based on this data, recommendations are made pertaining to the improvement of building/ structural design and construction practices. (419 pages)

Lew, H. S. (ed.). Wind and Seismic Effects: Proceedings of the Eighth Joint Panel Conference of the U.S. - Japan Cooperative Program in Natural Resources. National Bureau of Standards: Washington D.C. 1977. (GPO C13.10:477, $5.80).

Proceedings of the eighth joint meeting of the U.S. - Japan Panel on Wind and Seismic Effects including the papers presented at the meeting. (626 pages)

McCue, Gerald and Kost, Garrison. The Interaction of Building Components During Earthquakes. McCue, Boone, Tomsick: San Francisco. 1976. (NTIS PB258326, $7.75).

This report documents a study of the seismic interaction of building components with particular focus on the enclosure and finish systems. The results are intended to provide a problem overview and to develop a conceptual basis for solving the problem. (207 pages)

Murphy, Leonard M. (ed.). San Fernando, California Earthquake of February 9, 1971, Volumes I,II,III. National Oceanic and Atmospheric Administration, Washington, D.C. 1973. (GPO 0317-0087/0088/0089, $21.60/$11.70/$11.90).

Set of volumes documenting the extensive investigation of the San Fernando earthquake. Data and information is provided on the earthquake effects on buildings, operations and services, human reactions, etc. Extensive illustrations. (841 pages, 325 pages, 432 pages)

National Science Foundation and USGS. Earthquake Prediction and Hazard Mitigation Options for USGS and NSF Programs. NSF/USGS: Washington D.C. 1976. (GPO 038-000-00332-1, $1.90).

This plan presents options for augmenting the earthquake research programs of the U.S. Geological Survey and the National Science Foundation. (76 pages)

Newmark, N. W. and Rosenblueth, E. Fundamentals of Earthquake Engineering. Prentice-Hall, Inc.: Englewood Cliffs, New Jersey 1971.

Not reviewed

Nichols, D. R. and Buchanan - Banks, J. M. Seismic Hazards and Land-Use Planning. U. S. Geological Survey: Washington, D.C. 1974. (USGS Circular 690, Free). Contact: U. S. Geological Survey, National Center, Reston, Vriginia 22092.

This report outlines those earthquake induced geologic conditions that could be hazardous, the type of problems they pose, how information can be obtained to assess the degree of hazard, and some possible implications to land-use. (33 pages)

Nielsen, N. Norby and Furumoto, Augustine S. et al. The Honomu, Hawaii Earthquake. National Research Council: Washington, D.C. 1977. Contact: NAS, 2101 Constitution Avenue N.W., Washington, D.C. 20418.

Documentation of an investigation of the 1973 Honomu, Hawaii earthquake. (79 pages)

Panel on Earthquake Prediction. A Scientific and Technical Evaluation - With Implications for Society. National Academy of Sciences; Washington, D.C. 1976. Contact: NAS, 2101 Constitution Avenue, N.W. Washington, D.C. 20418.

This report evaluates the current state-of-the-art in earthquake prediction and assesses the outlook for the future. (62 pages)

Panel on the Public Policy Implications of Earthquake Prediction. Earthquake Prediction and Public Policy. National Academy of Sciences: Washington, D.C. 1975. Contact: NAS, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

This report deals with the role of governmental agencies in responding to earthquake predictions. Included are recommendations for governmental actions to mitigate the loss of life and property as well as further research and study needs. (142 pages)

Pregnoff, Matheu, Beebe, Inc. and Saphite, Lerner, Schindler Environetics, Inc. Earthquake Resistance of Buildings, Volumes I,II,III. General Services Administration: Washington, D.C. 1976. (PBS(PCD): DG.3, $1.10 each). Contact: Business Service Center, General Services Administration, 7th and D Streets, S.W., Washington, D.C. 20407.

Volume I "Design Guidelines" deals with both structural and nonstructural building components. Volume II "Evaluation of Existing Structures" presents a method of determining the damage potential of existing buildings for different levels of seismic activity. Volume III "Commentary on Design Guidelines" reviews current UBC requirements. (42 pages, 71 pages, 30 pages)

Rogers, A. M. et al. A Study of Earthquake Losses in the Salt Lake City, Utah Area. U.S. Geological Survey: Washington, D.C. 1976.

The purpose of the report was to provide essential data for effective pre-disaster planning for major damaging earthquakes that might affect the Salt Lake City Metropolitan Area. (357 pages)

Reed, Richard E. (ed.). Living With Seismic Risk: Strategies for Urban Conservation. American Association for the Advancement of Science: Washington D.C. 1976. (AAAS 77-R-1) Contact: American Association for the Advancement of Science, Washington, D.C. 20036.

Proceedings of a seminar held in 1976 dealing with hazard abatement strategies which acknowledge both the social values and economic realities of the inner city. (143 pages)

Reps, W. F. Design, Siting, and Construction of Low-Cost Housing and Community Buildings to Better Withstand Earthquakes and Windstorms. National Bureau of Standards: Washington, D.C. 1974. (GPO C13.29/2:48, $4.85).

This report provides information regarding the characteristics of materials and building systems, and discusses the performance of buildings subjected to earthquakes and wind forces with emphasis to buildings typical of developing countries. (132 pages)

Simonson, T. R. et al. Seismic Resistant Design of Mechanical and Electrical Systems. G.M. & T.R. Simonson, Engineers; San Francisco 1976. (NTIS).

This report presents the results of a study of various conceptual aspects of the dynamic interaction of building components during earthquakes, with emphasis on mechanical and electrical service systems. (215 pages)

Steinbrugge, Karl V. et al. The Santa Rosa, California Earthquakes of October 1, 1969. U.S. Department of Commerce: Washington, D.C. 1970. ($2.00).

A documentation of the effects of the 1969 Santa Rosa Earthquakes. (99 pages)

Steinbrugge, Karl V. et al. San Fernando Earthquake, February 9, 1971. Pacific Fire Rating Bureau: San Francisco 1971. Contact: Pacific Fire Rating Bureau, 465 California Street, San Francisco, California 94104.

This report analyzes the damage statistics and economic loss data of the San Fernando earthquake. A section emphasizes the damage to community lifelines. Extensive illustrations. (93 pages)

Sozen, Mete A. and Mattheisen, R.B. Engineering Report on the Managua Earthquake of 23 December 1972. National Academy of Sciences: Washington, D.C. 1975. Contact: National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418.

This report summarizes the results of a team inspection of the 1972 Managua earthquake. The documentation includes the strong-motion measurements of the earthquake as well as a description of structural damage. (111 pages)

Stone, Marraccini, and Patterson. Study to Establish Seismic Protection for Furniture, Equipment, and Supplies for VA Hospitals. Veterans Administration: Washington, D.C. 1976. Contact: Research Staff Office of Construction, Veterans Administration, Washington, D.C. 20420.

This report provides seismic design and protection considerations for essential equipment, furniture and supplies located in hospitals. (205 pages)

United Nations. Low Cost Construction Resistant to Earthquakes and Hurricanes. United Nations: New York 1975. (E.75.IV.7, $9.00). Contact: United Nations, Sales Section, New York, New York.

This report deals with design and construction issues which must be taken into account when building new low-cost buildings in areas stricken by earthquakes and strong winds. (205 pages)

U.S. Geological Survey. The San Fernando California Earthquake of February 9, 1971. U.S. Geological Survey: Washington, D.C. 1971. U.S. Geological Survey: Washington, D.C. 1971. (GPO, $2.25).

The major emphasis of this report is on the geologic effects of the San Fernando Earthquake, although specific examples of building damage is discussed. (254 pages)

White, Gilbert F. and Haas, J. E. Assessment of Research on Natural Hazards. The MIT Press: Cambridge 1975. Contact: The MIT Press, Massachusetts Insitute of Technology, Cambridge, Massachusetts 02142.

This report discusses and assesses present natural hazards research, future research needs and strategies and opportunities in natural hazards research. (487 pages)

Wiegel, Robert L. (ed.) Earthquake Engineering. Prentice-Hall: New Jersey, 1970. ($26.95). Contact: Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

A comprehensive book that covers a broad range of topics and aspects of earthquake engineering. Each chapter is written by a recognized expert in the field. (518 pages)

Wood, Fergus J. (ed.). The Prince William Sound, Alaska Earthquake of 1964 and After Shocks, Volume II, Part A. U.S. Department of Commerce: Washington, D.C. 1967. (GPO, $5.50).

This volume of a three volume set is prepared for the use of designers studying the effects of the Alaskan Earthquake upon various types of building construction. (392 pages)

Wright, Richard et al. Building Practices for Disaster Mitigation. National Bureau of Standards: Washington D.C. 1972. (GPO C13.29/2:46, $5.30).

Proceedings and papers of the National Workshop on Building Practices for Disaster Mitigation held in 1972. Recommendations are documented that evaluate current building practices, define improved practices and recommend future research. (483 pages)

Yanev, Peter I. Peace of Mind in Earthquake Country: How to Save Your Home and Life. Chronicle Books: San Francisco 1974. Contact: Chronicle Books, 870 Market Street, San Francisco, California 94102.

This book explains to the general reader the earthquake hazard to single-family residential buildings and what can be done to reduce these hazards. Extensive illustrations. (304 pages)

GOVERNMENT DISTRIBUTION

Superintendent of Documents
U.S. Government Printing Office (GPO)
Washington, D.C. 20402
(202) 783-3238

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, Virginia 22161
(703) 557-4650

MOVIES/SLIDES

"THE ALASKAN EARTHQUAKE" (1964)

Views of the destruction caused by the Good Friday earthquake, especially in the city of Anchorage. Some of the geological conditions which made the city especially vulnerable are explained. U. S. Geological Survey Production. 16mm color film, 20 minutes. Rent $5. Available through the University of Idaho, Audio-Visual Center, Moscow, Idaho 83843. Also available for $3 rent through the University of Maine, Film Rental Library, Orono, Maine 94473. Also available for $8 rent through the University of California, Extension Media Center, Berkeley, California 94720. Also available for $5 rent through the University of South Florida, Educational Resources, Tampa, Florida 33620. Also available for $6 rent through the University of Texas at Arlington, Division of Audio-Visual Services, Arlington, Texas 76019.

"THE ALASKA EARTHQUAKE, 1964" (1966)

Through a series of animated scenes, live-action footage, and models, the film shows the nature and causes of earthquakes and the locations of principal earthquake zones throughout the world. The disastrous effects of the 1964 Alaska earthquake on population centers, including Anchorage and Valdez, are shown, and the damage is explained in terms of geologic environment. 22 minutes. Available from Modern Talking Picture Service, Inc., 2323 New Hyde Park Road, New Hyde Park, New York 11040.

"CARACAS EARTHQUAKE" (1967-68)

Describes the characteristics of the Caracas, Venezuela, earthquake and discusses the codes, building types, and behavior of a great number of buildings during the quake. Set of 85 slides, with narration, number SS072, sale $111. Available through Photo Librarian, Portland Cement Association, Old Orchard Road, Skokie, Illinois 60076.

"COPING WITH QUAKES" (1971)

A documentary film on earthquakes, highlighting the Feb. 9, 1971 earthquake in Southern California. Shows how architects and engineers design for quake-prone country. Discusses advances in research, design, and code provisions to minimize structural damage and loss of lives. 16mm color film, 15 minutes, sale $170, rent $8. Available through Portland Cement Association, Old Orchard Road, Skokie, Illinois 60076.

"DESIGN vs. NATURE'S VIOLENCE"

How plywood structures withstood the 1964 Alaska earthquake, also how plywood's diaphragm action resists hurricane wind forces. For architects, engineers and building officials. 16mm black and white film, sound, 22 minutes. Free loan. Avialable through American Plywood Association, 1119 A Street, Tacoma, Washington 98401.

"THE DESTRUCTION OF SAN FRANCISCO -- 1906"

One of the greatest disasters in American history took place in San Francisco on April 18, 1906 at 5:13 am. The San Andreas fault slipped for a mere 55 seconds and the result cost the city 500 deaths and $420,000,000 in damages. 16mm, silent, bw, 26 minutes, rent $15. Available through Wayne State University, A-V Dept., 5448 Cass Avenue, Detroit, Michigan 48202.

"DISASTER AT DAWN" (1961)

Recreates the San Francisco earthquake of 1906 through film taken immediatley after the quake and during the fire. 16mm, 27 minutes, rent $7. Available through University of California, Extension Media Center, Berkeley, California 94720.

"THE DRIFTING OF THE CONTINENTS"

This film discusses the developments that have come from discoveries in paleomagnetism, oceanography and seismology and the effect on the earth sciences from geochemistry to earthquake engineering. 16mm, color, 50 minutes, rent $55.

"DUCTILE SHEAR WALLS IN MULTI-STORY BUILDINGS" (1973)

Illustrates the excellent performance of shear walls in the earthquakes of the last 10 years. Also discusses the state-of-the-art of the design of concrete shear walls for strength, stiffness and ductility. Set of 36 slides, with narration, number SS078, sale $50. Available through Photo Librarian, Portland Cement Association, Old Orchard Road, Skokie, Illinois 60076.

"EARTHQUAKE!" (1966)

Discusses the causes of earthquakes and describes modern techniques for detecting them. 16mm color film, 15 minutes. Rent $8.50. Available through Boston University, Krasker Memorial Film Library, 765 Commonwealth Avenue, Boston, Massachusetts 02215. Also available for $7 rent through the University of Southern California, Division of Cinema, Film Distribution Section, University Park, Los Angeles, California 90007.

"EARTHQUAKE" (1972)

Documentation of the earthquake in Southern California, telling the story of what happened when it struck, and how people and their governments responded. 16mm color film, 28½ minutes. Sale $96.25 from the National Audio-Visual Center, National Archives and Records Service, Washington, D.C. 20409. Free loan from nearest Army Audio-Visual Support Center (refer to No. DDCP-20-278).

"EARTHQUAKE" (1972)

This is a condensed version of the 28 minute film of same name. It has been prepared to permit increased showings on TV stations and before civic groups where program time is strictly limited. CINE Golden Eagle Certificate. 16mm color film, 13 minutes. Sale $50.50 from National Audio-Visual Center, National Archives and Records Service, Washington, D.C. 20409. Free loan from nearest Army Audio-Visual Support Center (refer to No. DDCP 20-280).

"EARTHQUAKE II: THE PEOPLE"

Effects of earthquakes on people, concern for future city planning and adequate building code requirements. 16mm color film, 20 minutes. Rent $25, sale $240. Available through ABC Media Concepts, 1330 Avenue of the Americas, New York, New York 10019. Also available for sale only ($295), through Xerox Films, 245 Long Hill Road, Middletown, Connecticut 06457.

"EARTHQUAKES: LESSON OF A DISASTER" (1971)

Seismologists demonstrate the use of P waves, R waves and other methods to determine an earthquake's occurrence, location, and magnitude through the case studies of two major quakes -- one in California and one in Turkey. Because of the frequency of major quakes, preearthquake planning, detection and emergency plans are stressed. 13 minute color film.

Rent $5.60 Available through the University of Arizona, Bureau of Audio-Visual Services, Tucson, Arizona 85721. Also available for $6.30 rent through the University of Illinois, Visual Aids Service, 1325 South Oak Street, Champaign, Illinois 61820. Also available for $12 rent through the University of California, Extension Media Center, Berkeley, California 94720. Also available for $6 rent through the University of Southern California, Division of Cinema, Film Distribution Section, University Park, Los Angeles, California 90007.

"IN THE WAKE OF THE QUAKE"

This film covers the Alaska Earthquake that occurred in 1964. A survey of the damage and actual photos of the earthquake itself are included. An architect prepared the film and it is used to promote masonry construction. B/W, 40 minutes. Information about the film can be obtained from Western States Clay Products Association, 55 New Montgomery Street, San Francisco, California 94105.

"LOS ANGELES EARTHQUAKE" (1971)

Illustrates the general characteristics of the Los Angeles, California earthquake and gives a detailed report on the behavior of many buildings during the quake. Set of 73 slides, with narration, number SS073, sale $113. Available through Photo Librarian, Portland Cement Association, Old Orchard Road, Skokie, Illinois 60076.

"THE MANAGUA EARTHQUAKE"

The Managua, Nicaragua earthquake occurred on December 23, 1972. With a magnitude on the Richter scale of 6.2, it resulted in enormous damage and a loss of an estimated 10,000 lives. Includes examples of damage to the city. 24 color slides with printed narration, sale $24. Available through James L. Ruhle & Assoc., P.O. Box 4301, Fullerton, California 92631.

"MEN, STEEL AND EARTHQUAKES" (1953)

Causes, measurement, building collapse, research are discussed. See how the correct structural design and the proper use of steel in all types of buildings have proved effective in resisting the effects of earthquake shock. 16mm color film, sound, 28 minutes. Available through Bethlehem Steel Corporation, Advertising Division, 701 East

Third Street, Bethlehem, Pa. 18016, or through Modern Talking Picture Service, 1212 Avenue of the Americas, New York, New York 10036.

"THE NOT SO SOLID EARTH"

The film traces one of the most revolutionary findings of this century: the discovery of powerful forces deep within the earth that move continents and shift oceans. The film shows how geologists, oceanographers, paleontologists and mineralogists gather and analyze supporting data for the theory of "Continental Drift." The film shows erupting volcanoes and earthquake destruction plus the dynamic system which is reshaping the earth's surface. 16mm, color, 30 minutes, rent $40.00. Available through Time-Life Films Multimedia Division, 100 Eisenhower Drive, Paramus, New Jersey 07652.

"PROTECTIVE CONSTRUCTION"

Precise data on construction that will withstand nuclear and/or natural disasters. Discusses several varieties of shelters. Through test results, determines clay masonry to have inherent strength which can be utilized to resist these dynamic forces. Set of 40 color slides, with script, sale $20. Available through the Brick Institute of America, 1750 Old Meadow Road, McLean, Virginia 22101.

"THE SAN ANDREAS FAULT OF CALIFORNIA"

The most conspicous rift of its kind in the world. This spectacular geological feature, which has created much of California's scenic beauty, has been storing vast amounts of energy during the last 200 years. When the energy is unleashed, the result will be disaster. 50 color slides with printed narration, sale $50. 50-frame filmstrip with cassette, narrated by Rod Serling, sale $25. Available through James L. Ruhle & Associates, P.O. Box 4301, Fullerton, California 92631.

"THE SAN FERNANDO EARTHQUAKE OF CALIFORNIA"

This earthquake occurred on Feb. 9, 1971, with a magnitude on the Richter scale of 6.6. It resulted in about 500 million dollars worth of damage and a loss of 60 lives. 36 color slides with printed narration, sale $36. Available through James L. Ruhle & Associates, P.O. Box 4301, Fullerton, California 92631.

"THE SAN FRANCISCO EARTHQUAKE"

Edison cameramen reached San Francisco after the fire and recorded damage and rebuilding. 16mm, 9 minutes, rent $15. Available through Film Classic Exchange, 1926 South Vermont Ave., Los Angeles, California 90007.

"SAN FRANCISCO: THE CITY THAT WAITS TO DIE" (1971)

According to scientists, San Francisco is a doomed city. A sudden shifting of the San Andreas Fault causing a catastrophic earthquake could reduce the city to rubble. In a race against time and public apathy seismologists have begun experiments to determine if man can control earthquakes. 16mm, color, 57 minutes, rent $23.50. Available through University of Iowa, A-V Center Media Library, C-5 East Hall, Iowa City, Iowa 52242. Also available for $50 rent through Time-Life Films Multimedia Division, 100 Eisenhower Drive, Paramus, New Jersey 07652.

"SKOPJE EARTHQUAKE" (1963-64)

Shows the earthquake in Skopje, Yugoslavia, in general; classifies the building categories; and discusses the behavior of a number of important buildings during the quake. Set of 33 slides, with narration, number SS071, sale $43. Available through Photo Librarian, Portland Cement Association, Old Orchard Road, Skokie, Illinois 60076.

"WARNING EARTHQUAKE"

Illustrates the destructive power of earthquakes with scenes from Turkey, Chile, Italy, Alaska and California. Topics include new developments in earthquake prediction. California research involving building construction and city design and interviews with earthquake survivors. 16mm, color, 22 minutes, rent $25, sale $320. Available through Encyclopaedia Britannica Educational Corporation, 425 N. Michigan Avenue, Chicago, Illinois 60611.

ABSTRACTS/INFORMATION SERVICES

Abstract Journal in Earthquake Engineering.
Earthquake Engineering Research Center
University of California, 47th Street and Hoffman Boulevard
Richmond, California 94804
Published annually $20.00

"Building Technology Publications: 1976."
National Bureau of Standards. (GPO 003-003-01802-3, $2.20)

Directory of Disaster-Related Technology
U.S. Department of Housing and Urban Development
Federal Disaster Assistance Administration
Washington, D.C. 20410
(401-FDAA, $8.95)

Earthquake Engineering Research Center Library Printed Catalogue.
EERC Library, 1301 South 46th Street
Richmond, California 94804

"Grants and Awards for Fiscal Year 1975."
National Science Foundation
Washington, D.C. 20550
(GPO 038-000-00261-9, $3.10)

National Information Service for Earthquake Engineering (NISEE)
California Institute of Technology
Pasadena, California

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NTIS is the central source for the public sale of Government-sponsored research reports.

Smithsonian Science Information Exchange (SSIE)
SSIE, Room 300, 1730 M Street, N.W.
Washington, D.C. 20036

SSIE supplies information searches on ongoing research projects.

PERIODICALS

"Disasters - The International Journal of Disaster Studies and Practices". Pergamon Press, Fairview Park, Elmsford, New York 10523. Published quarterly ($44.00)

"Earthquake Information Bulletin". U.S. Geological Survey, National Center (904), Reston, Virginia 22092. Published bimonthly (2.50)

"EERC News". Earthquake Engineering Research Center, University of California, 47th Street and Hoffman Boulevard, Richmond, California 94804. Published quarterly (free)

"EERI Newsletter". Earthquake Engineering Research Institute, 11972 Chalon Road, Los Angeles, California 90049. Published bimonthly to members.

"Natural Hazards Observer". Natural Hazards Research and Applications Information Center, Institute of Behavioral Science #6, University of Colorado, Boulder, Colorado 80309. Published quarterly (free)

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