LONG BEACH EARTHQUAKE

and

PROTECTION AGAINST FUTURE EARTHQUAKES

Summary of Report by
Joint Technical Committee on Earthquake Protection
Dr. Robert A. Millikan, Chairman.

To the Public of the Pacific Southwest:

In response to official requests from many representative technical and civic organizations, the Joint Technical Committee on Earthquake Protection was organized after the earthquake of March 10, 1933 to consider ways and means of minimizing loss of life and property damage in the event of another earthquake of equal or greater intensity.

We now present to you, in the form of this summarized report, our belief as to the seismic hazard in this region and our opinion as to the proper balance between the degree of protection to be afforded life and property and the cost of providing such protection.

We sincerely hope that the lessons of the Long Beach earthquake will not be forgotten as were the lessons which should have been fixed indelibly in the minds of all by the earthquakes of the past.

JOINT TECHNICAL COMMITTEE
ON EARTHQUAKE PROTECTION

Robert A. Millikan
Chairman.

June 7-1933.

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Immediately after the Long Beach earthquake of March 10, 1933, committees of several technical societies and other interested bodies in southern California commenced investigations to determine the effect of the earthquake, the reasons for the large loss of life and severe property damage, and the steps which should be taken to minimize the effects of future earthquakes.

Necessity for correlation of the efforts of the various investigating groups was soon recognized, and a permanent general committee known as "Joint Technical Committee on Earthquake Protection" was formed under the chairmanship of Dr. Robert A. Millikan of California Institute of Technology.

Although many months will be required to complete the detailed investigations now being carried on by these organizations, the essential conclusions as to what happened, why it happened, and what should be done to prevent loss of life and property in the future are now known. In order that this information may be available to the public in general and to governing officials in particular, this summary is presented in advance by the Joint Technical Committee on Earthquake Protection.

Due to the nature of this report, the Committee has generally restricted itself to consideration of the earthquake hazard in the densely populated coastal region of which Los Angeles is the economic center, although most of its conclusions and recommendations are applicable to all of California and to all other parts of the Pacific Southwest.

In their natural order, the work of the Committee will consist in correlation of investigations already made or now being carried on, as to

(a) The general seismic activity of this part of the continent; the geology of southern California with particular reference to the location and activity of fault zones; the location and character of areas of deep alluvium; the extent of areas where groundwater is close to the surface; and the occurrence of adverse foundation materials for structures.

(b) The relation between the geographic distribution of damage relative to the epicenter of the earthquake and the geologic and foundation characteristics of the particular area; the relation between types of structures and the extent of damage in areas subjected to like intensity of shock, with special consideration to particular causes of loss of life.

(c) The minimum intensity and duration of earthquakes to be anticipated in all provisions for earthquake protection.

(d) The minimum horizontal force which should be provided for in structures in all parts of this region, and which should properly be covered by legally adopted building codes, together with the amount of additional horizontal force which should be considered in the design and construction of public buildings and other structures where large numbers of people congregate; and likewise the additional horizontal and other forces which should be provided for in the design and construction of all types of structures located in areas subject to special hazard.

(e) The degree to which existing structures of public assembly, particularly schools, should be strengthened in order to insure against loss of life in event of an earthquake of the intensity and duration to be expected.

(f) Means whereby a conflagration resulting from an earthquake may be avoided.

The final report of the Joint Technical Committee on Earthquake Protection will include a general review of the detailed technical reports on the Long Beach earthquake which are to be presented by the various scientific, technical, and construction groups, and thus it will be much more detailed and more technical in its nature than this preliminary report. However, it is believed that this summary will afford the people of

Los Angeles and other communities a sound basis for the correction of weaknesses in existing structures and for the construction of new buildings and other works in regions of seismic activity.

GEOLOGICAL AND SEISMOLOGICAL CONSIDERATIONS

Earthquakes are a phenomena of common occurrence in many parts of the world. In certain localities seismic disturbances originate from volcanic action but more generally as a result of nature's process of continent building. While in some other parts of the world, earthquakes are accompanied more or less habitually by tidal waves, following none of the many earthquakes along the California coast has there been any serious disturbance of the sea, with the possible, but doubtful, exception of a small wave following the very severe earthquake of 1812.

Other earthquakes originating on any of the numerous fault zones in California and other parts of the Pacific Southwest are to be expected from time to time. These may well occur close enough to populated areas to make it imperative that consideration be given to the extent of the seismic hazard and to means of minimizing loss of life and damage to property.

Fault Structure

Nearly all earthquakes are caused by the slipping of one crustal block past another along a dividing fracture or fault. In southern California the region from the Mojave Desert to beyond the off-shore islands is traversed by a series of active faults. These extend from a few tens to many hundreds of miles in length and the trend is generally between north and west; however, they are only roughly parallel and in certain instances a major fault divides into two or more well defined fault zones. In general these faults are from five to twenty miles apart and apparently extend to depths of fifteen or more miles below the surface of the earth.

From northeast to southwest they are the San Andreas, San Jacinto, San Gabriel, Sierra Madre, Raymond, Whittier-Elsinore, and Inglewood, with several unnamed faults off-shore. The structure of southern California hence consists of a series of northwestward-trending blocks or crustal slices five to twenty-five miles wide, fifteen or twenty miles thick, and tens to hundreds of miles in length. Since the faults are not parallel, these great blocks or slices are often shaped like a wedge.

Prehistoric Earthquakes

Earthquakes have occurred in California for a long period in the geologic past and it is extremely probable therefore that they will recur from time to time in the future. Their occurence in prehistoric times is attested by the bodies of crushed and pulverized rock found along the active faults, resulting from the grinding during numerous previous movements; by the offset of geological formations and the uplift of mountain blocks, indicating total displacements explicable only by many repeated slips and consequent earthquakes; by the distorted topography and structure along the faults, and by streams offset horizontally or vertically.

Historical Earthquakes

The historical record likewise testifies to the continuance of such movements which from time to time produce earthquakes. In the southern coastal section shocks of large magnitude were recorded in 1769, in 1812, and in 1857, and other very severe earthquakes have occurred in the northern part of the state and in the desert regions to the east. In addition to the three major shocks in this region, several scores of earthquakes of locally destructive intensity have occurred. In some cases these shocks of moderate magnitude severely damaged property and caused some loss of life but fortunately, in many cases, the center of the earthquake was in a very sparsely settled region.

The Long Beach earthquake of March 10, 1933 was one of only moderate magnitude as compared with other shocks which have occurred in California and in other parts of the world. Its origin was beneath the sea about four miles southwest of Newport Beach and it was caused by a slip on a submarine fault, presumably on a fracture along the southern extension of the Inglewood fault zone.

Future Earthquakes

It is not possible to make definite predictions as to either the time at which an earthquake will occur or as to the intensity and duration of a future shock. While the geological record extends over a very great length of time, the historical record covers only two centuries. It is certain, however, from the continuous records at the seismographic stations in Southern California and other areas, that this region is seismically very active.

The three most severe shocks which have occured in the Southern portion of this State were not of as great magnitude as earthquakes that have occured in the Orient, in Southern Europe, in South America, and even in the Central and Eastern parts of the United States. These earthquakes of historical record, however, were much greater in intensity and would have caused much greater damage than the Long Beach earthquake, and it is not improbable that an even stronger earthquake may occur some time in the future.

Variations in Risk

Contrary to popular conception, the hazard of destruction by an earthquake is not limited to the area along a fault. Actually, the earthquake risk in Southern California varies somewhat from place to place but does not differ greatly. Instead of the destructiveness of a shock being greatest close to a fault upon which a slip occurs, very commonly the damage is greater at some localities located much further away from the origin of the earthquake. It is also clear that a violent disturbance on any one of several more distant faults may affect a locality more seriously than a less vigorous disturbance on a nearby fault.

In this region there are a number of geological peculiarities which greatly influence the intensity of an earthquake in any particular area. The Tertiary sedimentary rocks, which overlie the granitic bedrock or basement complex, range in thickness from zero to 30,000 feet or more. Where the thickness of these sedimentary deposits is greatest, the violence of shaking in a given shock will be most intense. Probably the most important factor affecting variations in risk is the thickness and the character of the recently deposited and relatively uncompacted alluvium; the thicker these deposits and the finer the grains of the material, the more subject it is to the development of large and destructive secondary waves during an earthquake. Similar intensification of an earthquake shock occurs where the groundwater is close to the surface and conversely the dryer the sub-soil the more stable will be the ground during a shock. Another variable element is the presumable but unpredictable occurence in any earthquake of nodal and anti-nodal points at which surface vibrations produced by the earthquake reinforce or cancel each other.

Consequently, there are many factors which tend to produce very irregular geographic differences in destructive effects. In general it must be considered that the risk of damage during an earthquake does not differ greatly throughout this entire region, even though there was marked variation in the degree of destruction at different localities during the Long Beach earthquake. The general risk from future shocks determined by variable combinations of these factors, including the location of the particular fault on which the disturbance may occur and the position of the epicenter on that fault, the intensity of the shock and its duration, the underlying rock formations, the depth and fineness of the alluvium, the distance to water, and possible nodal points, is so uniform that there is little justification for consideration of variations excepting where there is an unusually unfavorable combination of risk factors. On the other hand, when considerable freedom of choice exists as between sites and the construction of a building or other structure embodying in one case a combination of favorable factors and in the other an unfavorable set, it would seem desirable to exercise that choice.

Protection Required

There is reasonable probability, if not virtual certainty, that at some time in the future an earthquake of destructive intensity will originate on a fault sufficiently close to a center of population to cause great loss of life and damage to property, unless adequate protective measures are carried out. The fault structure of the region, its geological and historical earthquake record, are evidence of the possibility of the occurrence at any time of a shock of not less strength nor of less duration than the San Francisco earthquake of 1906. Any locality may be subjected to that intensity of shock either by a moderate earthquake on a nearby fault or by an earthquake of greater magnitude originating on a more distant fault.

The destruction experienced in the San Jacinto earthquake of 1899, in the San Francisco earthquake of 1906, in the Inglewood earthquake of 1920, in the Santa Barbara earthquake of 1925, and in the Long Beach earthquake of this year - not to mention certain earlier and other less well-known disturbances - should be sufficient warning, especially when almost no community in this entire region is many miles from an active fault. Even though local geological and other conditions appear favorable, a heavy shock originating on a fault at some distance might well be destructive to any building or other structure which has not been designed and constructed to be earthquake resistant.

<u>Summary</u>

Certain fundamental conclusions are evidenced by years of geological and seismological investigations in California and other parts of the Pacific Southwest.

(a) Earthquakes of damaging or destructive intensity will continue to occur in California from time to time in the future.

(b) An earthquake of the intensity and duration of the San Francisco earthquake of 1906 must be anticipated in this region.

(c) The risk of damage or destruction of buildings and other structures, and attendant loss of life, varies somewhat but not greatly throughout this region.

(d) The degree of risk is such that earthquake resistant construction is absolutely necessary in this region in order to avoid great loss of life and heavy damage to property.

EFFECT OF LONG BEACH EARTHQUAKE

At 5:54 in the afternoon of March 10, 1933, an earthquake of moderate magnitude caused severe loss of life and heavy property damage in Long Beach and neighboring communities. This earthquake should not have been unexpected, for it was typical of many others which have occurred in California and other parts of the Pacific Southwest and there was ample reason to have anticipated a slip along any one of the numerous faults which traverse this region. Nor should the resulting damage have been unexpected, for almost no provision had been made in the design and construction of buildings and other structures to resist such seismic shocks.

Areas Affected

Seismographic records indicate that the epicenter of the earthquake of March 10th was several miles off shore from Newport Beach on the Inglewood Fault. Although the center of the shock was thus about fifteen miles southeast of Long Beach, severe damage occurred almost as far northwest as Inglewood, and equal destruction occurred in areas more than ten miles laterally from the fault and generally in a zone several miles in width.

Had there been no differences in the geological character of the region, zones of equal intensity of shock and of approximately like damage would have been somewhat elliptical in shape, extending further along the fault zone than laterally. However, material differences do exist, principally in the form of deep alluvial basins and areas where groundwater is relatively close to the surface.

The combination of these adverse factors largely accounts for the severity of damage in Compton, Huntington Park, and numerous other communities located northeast of the Inglewood Fault in the alluvial filled valley which form the coastal plain. In contra-distinction, there were other areas, such as Laguna Beach and a large part of San Pedro, where bedrock is close to the surface of the ground, which suffered comparatively little damage although as near to the center of the shock. In Long Beach there was markedly more damage in those sections where the alluvium was deep and saturated than in the Signal Hill section, although the latter is closer to the actual trace of the fault upon which the slip occurred.

In general, the zone of severe damage extended longitudinally from Seal Beach almost ot Inglewood and from the ocean to a general line through Huntington Park and Santa Ana, with the greatest destruction in Long Beach and Compton. Southwesterly of the fault zone moderate damage occurred in San Pedro and in the area north of the Palos Verdes Hills, but the effect was slight elsewhere. Northeasterly of the Inglewood Fault, however, the zone of moderate damage was more extensive, in that it included the business district and the southern part of the City of Los Angeles and most of the towns located on the coastal plain in Los Angeles and Orange Counties.

Damage to Structures

In zones of equal intensity of shock there was wide variance in the degree of damage to structures. Certain types of buildings were comparatively little affected, while other types generally suffered greater proportional damage; some materials of construction seemed to withstand the shock far better than others; however, the essential distinctions were largely matters of inherent stability and attention to detail.

Damage to buildings of the same general type differed widely, depending upon the intensity of the shocks; furthermore, the relation between the extent of damage to structures of different types was far from constant. In some areas subjected to moderate shock a combination of circumstances peculiarly unfavorable to high skeleton frame buildings apparently developed, although low bearing wall structures in the same areas were little affected. On the other hand, in localities where the intensities were greater, the latter class of structures suffered much more proportional damage.

Most of the modern office buildings in the zone of severe damage were of fire-proofed skeleton frame construction, and these buildings suffered little or no damage other than to filler walls and partitions. Other major buildings of the same type of construction, but somewhat discontinuous in form and thus with less inherent rigidity, were injured more severely and there were extreme instances of serious damage. While conjectural, the damage to such buildings - built almost without regard for earthquake forces - would very probably have been much more serious and extensive had the earthquake been one of the intensity and duration to be anticipated

Although very little damage was done to buildings of the bearing wall type in areas where the shock was not intense, the characteristic degree of injury to this type of structure rapidly mounted toward the center of severest damage, and throughout the areas subjected to intense shock these buildings were generally incapable of resisting the force of the earthquake.

Had the Long Beach earthquake been of greater intensity, or of equal intensity over a larger area, damage to buildings of the bearing wall type would almost certainly have been widespread, and total collapse would have been of frequent occurrence.

Only general mention need be made of an all too prevalent class of construction in this region; namely, the stores and apartment houses which were built as cheaply as inadequate building codes would permit by those who were interested only in speculative profits. In the outlying sections of the major cities and generally throughout the small towns in the zone of severe damage, hundreds of such examples of unsound building construction were wrecked, and as a class they account for a large part of the toll of property damage.

While a great many of the residences in the affected area were likewise built to sell, they were almost universally of wood-frame construction. A certain amount of diagonal bracing is unavoidable in the erection of a wood-frame structure, and the weight of the building is small, consequently the inherent stability of single family residences is high. Except where the foundation walls were not carried up to the floor level and the underpinning was not braced, injury to this type of structure was largely limited to cracked plaster, to tile roofs, and to brick chimneys.

Electric power service was interrupted only a few minutes even in the zone of severe damage, excepting for a small part of Signal Hill where the power was off for more than an hour. However, gas was not distributed throughout Long Beach and other areas for a number of days; and there were some breaks in domestic water supply systems. Industrial plants of modern framed construction were not damaged severely, except in the case of certain plants located in what had been swampy areas and in others where heavy machinery was installed at a considerable height above the foundations without adequate diagonal bracing. Oil tanks were rarely damaged, except for the roofs on many large tanks. Oil pipe lines and other pipe lines were not generally affected, except in limited areas where displacement of the ground surface occurred. A few water towers were thrown down, but most of the damage to this type of structure consisted in distortion of supporting members. Docks and other harbor works supported on piles were generally displaced to some extent, and the level of fills behind bulkheads was lowered. Highways and bridges were substantially undamaged, except where built on fills across marshy or soft ground

Damage to Schools

More significant than the damage to commercial buildings, residences, and other types of structures, was the exposure of the general weakness of the schools in which the children of all families congregate each day. In Long Beach, in Compton, in Huntington Park - in fact in every community where the earthquake was at all intense - severe damage to school buildings was general. Auditoriums collapsed, walls were thrown down, and the very exits to safety were piled high with debris which a few moments before had been heavy parts of towers and ornamental entrances. It is sufficient to suggest the terrible consequences, had the same earthquake occurred a few hours earlier.

Faced with the necessity of providing space to take care of the tremendous increase in number of school children during the past fifteen years, desirous that such buildings should be attractive, and subject to a public opinion uninformed as to earthquake risk, Boards of Education were evidently most concerned with the size of the school buildings and their appearance. Actual or assumed financial limitations prevented the selection of the best type of construction, and legal requirements forced the letting of contracts to the lowest bidder who could secure bond. It is evident that this point of view is unsound and the economy false.

Loss of Life:

At 5:45 in the afternoon the school buildings were fortunately empty of children, and most of the adult persons in the area were at home. In spite of this, approximately one hundred and twenty people were killed outright or died of injuries, and many more were severely hurt. No precise estimate can be made, but it is clear that a very large proportion of the total deaths and injuries resulted from debris falling on people who were in the streets at the time, or who ran out into the streets at the first shock.

Much of this debris consisted of bricks from parapet walls; poorly supported cornices contributed to the mass of falling objects; and front walls of shops toppled off of their girder supports and crushed anything beneath. Occasional injuries and a few deaths occurred in residential areas, generally due to collapse of chimneys. Loss of life or severe injury to persons in well constructed buildings was very limited, if not entirely absent.

Necessary Conclusions:

Analysis of the effect of the earthquake of March 10, 1933 leads inevitably to the conclusion that:

(a) Damage to buildings and other structures and loss of life and injury to persons are not restricted to a narrow strip along a fault zone.

(b) Structures built on soft ground or in areas of deep alluvium, are adversely affected.

(c) In the areas subjected to intense shock, fire-proof skeleton-frame buildings suffererea less proportional damage than buildings of the bearing wall type.

(d) Well braced wood-frame residences were particularly resistant to the shock, except for the collapse of chimneys.

(e) All types of structures where cheapness had been the governing factor suffered severely.

(f) School buildings were generally unable to resist the force of the earthquake where the shocks were at all intense, and all similarly constructed school buildings must be considered incapable of resisting an earthquake of destrictuve intensity.

(g) Loss of life was much less than would have been the case if the earthquake had occurred a few hours earlier. Such loss of life and injury to persons as did occur was due largely to falling debris, particularly from fire walls, cornices, and other ornamentation, and from the outward colla pse of poorly supported masonry, tile and brick walls.

(h) All buildings should be and school buildings must be so re-designed and strengthened that a repetition of the recent disaster can not take place.

STANDARDS FOR DESIGN OF STRUCTURES

An earthquake of the intensity and duration of the one which did so much damage in San Francisco and neighboring communities in April 1906 may occur at any time in the future in any part of the Pacific Southwest. Damage to buildings and other structures in San Francisco, in Santa Barbara, and in Long Beach, and similar destructive effects during earthquakes which have occured in other parts of this country and foreign countries, is ample evidence that designs which do not include allowance against forces produced by earthquakes are not satisfactory.

Any structure is subjected to abnormal stress during an earthquake, and unless special provision is made in the design, partial failure or complete destruction may well result. The forces resulting from a shock are extremely complex; furthermore, the problem is a dynamic one in that the direction of these forces repeatedly changes during an earthquake. Any attempt, however, to measure the dynamic forces involved and to consider a structure as a vibrating unit has been found to be generally impracticable.

In this connection, John R. Freeman, who was one of the greatest students of the problem, stated:

"Just as 24 years ago I concluded that the behavior of the flat arch in the ancient Church of San Domingo at Panama told a more credible story about absence of violent earthquakes on the Isthmus by its survival of more than 200 years, than could be found in the monographs of geologists, so I now conclude that the almost perfect resistance to the violent Japanese earthquake of September 1, 1923, by many tall, carefully built, rigid office buildings, warehouses, etc., in Tokyo, which had been designed to everywhere resist a horizontal force equal to 10 per cent of the superincumbent weight at each floor-level (or 1/10th the acceleration due gravity), and considering that this successful resistance was against far greater earthquake forces than those of Charleston, San Francisco and Santa Barbara or any other of which we have evidence in the United States, gives an ample basis for trusting to . . . . safe and simple rules, particularly in the United States and Canada."

This is also endorsed by Prof. Suyehiro, an outstanding Japanese authority, who stated in reference to the Tokyo earthquake:

"As a practical problem, the actual fact that buildings designed under 'the 0.1g basis' resisted this earthquake fairly well is a datum more valuable than any other arguments."

Acceleration of Earthquakes

It is generally recognized that the acceleration of a destructive earthquake has never been measured with tolerable accuracy anywhere within the zone of severe damage. However, it is probable that the acceleration during the San Francisco earthquake was in some places as high as 40 per cent of gravity, and that over a large part of the area the acceleration approximated at least one-tenth gravity. During the Santa Barbara and Long Beach earthquake, which were substantially of the same intensity, an acceleration of about 20 per cent gravity occurred in a few localities, but in general the intensity was probably less than one-tenth gravity. The Tokyo earthquake, on the other hand, was of considerably greater intensity than that in San Francisco.

The sensible duration of the San Francisco earthquake was about one minute, that in Tokyo was several minutes, while the larger shocks in Long Beach earthquake lasted only thirteen seconds.

In order that an earthquake of the intensity and duration of that which occurred in San Francisco in 1906 might be resisted by buildings and other structures, it is evident that an acceleration equal to one-tenth of that due to gravity must be assumed in the design of such structures. Following the simple rule which has been found to be applicable, the forces produced by the earthquake may properly be considered as a horizontal force applied against any building equal to one-tenth the superincumbent weight above the point application of the force.

This rule is likewise applicable to almost any other type of structure, although in the case of masonry dams and other structures which tend to slide, and under certain adverse conditions, special consideration should be given to vertical acceleration opposing gravity. In general, however, intelligent application of the "0.1 gravity rule" will result in a safe structure.

Allowable Stresses and Load Reductions

In Japan, as a result of experience gained in the Tokyo earthquake and other severe earthquake, the factor of one-tenth gravity has been generally applied, and no increase in working stresses in the materials is allowed, nor is any reduction made in the live load which is, of course, a part of the superincumbent weight.

In Italy the likelihood of severe earthquakes more nearly approximates conditions in Japan, and the design requirements are of substantially the same character. In New Zealand the same acceleration or horizontal force is assumed, but the hazard being considered less than in Japan, momentary increase in the working stresses of materials is permitted.

The chance of an earthquake in this region of the intensity and duration of that which occurred in Tokyo is believed small enough to warrant momentary increase in the unit stresses and the assumption of reduced live loads.

Aside from lateral pressure due to wind, substantially all esisting buildings and other structures were designed to support the wright of the building and other loads which were assumed to act only in vertical planes. It is usual in such designs against vertical loads to provide a factor of safety of three or four; that is, the stress in columns and in other structural members is not permitted to be more than about one-third of that which would cause failure. Consequently, when horizontal forces are considered as being applied to the structure over a short period of time, it is reasonable that the unit stress in the various members should be increased by one-third.

It must be recognized, however, that a horizontal force equal to one-tenth the superincumbent weight will increase the unit stress in many parts of the structure far more than one-third, unless special provision has been made in the design.

Live loads, that is, any load or weight other than the actual weight of the structure itself, are generally based upon the maximum condition which may occur. In warehouses the live load frequently is as great as assumed in normal design of such buildings, but in office buildings, stores, theaters, and schools, only extreme congestion of persons would produce the loads assumed in ordinary design. The likelihood of all parts of such buildings being loaded to a maximum simultaneously is naturally remote; consequently, in considering the resistance against earthquake shock in this region, it is entirely proper that the maximum live loads should be reduced by one-fourth to one-half.

Distribution of Forces

Irrespective of the direction in which a force is exerted against a structure, generally it must be carried vertically downward to the foundation. On this account the vertical supporting members, particularly the columns and walls, must be so designed as to resist the bending produced by the horizontal force resulting from an earthquake. In order that such horizontal forces may be transmitted to the vertical members capable of taking this force, all connections must be capable of resisting the shearing stresses involved, and each floor, roof, or other horizontal system must be made rigid by proper diagonal bracing or by other means.

Where structures are built on loosely consolidated material, or when they are supported on piles or caissons, the foundations should likewise be inter-connected, so as to resist horizontal movement.

Complexity of Design

In its primary elements, the design of a new structure to resist forces produced by an earthquake, and the analysis of the ability of an existing structure to resist such forces, consist in the determination of:

(a) Strength and physical properties of the materials of construction;

(b) The total weight above each floor or other level;

(c) The distribution of the horizontal forces - expressed as a percentage of the superincumbent weight - to the walls and columns supporting the structure in proportion to the relative stiffness of these members;

(d) The combined stress due to vertical and horizontal loads in each member with consideration of the torsional effects where the applied force is not coincident with the resisting member;

(e) The details of connections between members necessary to knit the entire structure into a homogeneous unit.

Recommended Standards

Except for certain special types of construction, such as well braced, wood fram residences, it is recommended that all existing buildings be brought up to the following standards, and that in the design of all new buildings the following should be considered the minimum standards:

(a) Horizontal Forces

In the design of buildings, and all other types of structures which extend above the surface of the ground, a horizontal force of at least one-tenth that due to gravity, that is, one-tenth of the superincumbent weight, should be assumed.

Special structures and parts of structures, such as tanks, towers, chimneys, smokestacks, pent houses, etc., should be designed to resist a horizontal force of not less than one-fifth of their weight.

All fire walls, parapet walls, and other similar walls, and all exterior ornaments and appendages, should be designed to resist a horizontal force equal to the full weight of such walls, ornaments, or appendages.

(b) Live Loads

The live loads to be used in designs for earthquake protection should be not less than one-half the live loads used in design of buildings, bridges, and other structures for vertical forces, except that no reduction in live load should be made in the case of warehouses and other structures normally subjected to full live loads.

(c) Combined Stresses

The combined stresses due to vertical and horizontal forces should not exceed by more than one-third the maximum unit stress allowed in designs for vertical forces only. Such combined stress should in no case be more than 50 per cent of the ultimate strength of any material of construction in compression, tension, or shear.

STRENGTHENING OF EXISTING BUILDINGS

In several foreign countries, especially in Japan, Italy, and New Zealand, standards of design have been adopted with respect to buildings which render all new buildings resistant to earthquake shocks. In this country, but slight consideration has been given to the special problem of design against earthquake shocks. Palo Alto and Santa Barbara were the only cities - until very recently - which had adopted adequate standards; however, this was only after a destructive earthquake in each case.

Any building code adopted as part of the law of any community is applicable to all new construction, but perhaps such laws cannot be made retroactive. This situation is of tremendous importance for the number of buildings already existing is many times the number to be built during the next ten or twenty years. Presumably, as such buildings become obsolescent they will gradually be replaced by new structures built according to proper standards, but it must be recognized that there will be the continued hazard of partial or total destruction of thousands of privately owned buildings in California and other parts of the Pacific Southwest. Correction of this condition by the strengthening of all privately owned buildings will be largely at the volition of the owner.

However, much can be done under the police power of each community to eliminate actual hazards to life.

Such legal restrictions on the retroactivity of laws, however, do not apply to existing public buildings. Many such buildings would be unable to withstand an earthquake of even the intensity of that which occurred in Long Beach on March 10, 1933, and would almost certainly be greatly damaged, if not entirely destroyed, in an earthquake of the intensity and duration of that which occurred in San Francisco in April 1906.

A large proportion of the total investment in public buildings is in the schools. In California the increase in population was extremely rapid during the past fifteen years and necessarily there was a great expansion in school facilities on that account alone. In addition, the tendency toward an expanding curriculum was greatest during the same period, with the result that the capital investment in school buildings at the present time averages almost $50 per capita throughout this state and is more in the metropolitan centers. The weakness of most school buildings has been demonstrated beyond question by the failure of a large proportion of such buildings to resist the earthquake in Long Beach and neighboring communities. To make all schools and other public buildings safe in event of an earthquake will involve the expenditure of large sums.

Basis of Original Designs

Practically all buildings have heretofore been designed and constructed to resist only the vertical forces produced by the weight of the building itself and the other vertical loads which might be brought to bear. As evidenced by the destruction to such buildings in every earthquake of magnitude, this practice has resulted in structures incapable of withstanding even relatively slight horizontal forces.

School buildings, in particular, suffered excessive damage in the Long Beach earthquake, due primarily to the fact that most of these buildings were so built and the materials of construction were such that horizontal forces could not be resisted, and secondarily to the character of such buildings which normally were provided with high ceilings and large rooms, with the wall area greatly reduced by large windows.

It is not to be presumed, however, that buildings of the same architectural form cannot be made to withstand earthquake forces, nor is it to be presumed that existing buildings of this type cannot be strengthened in most cases so as to be reasonably safe in event of a severe earthquake. The problem, however, is complex and a high order of technical design and execution will be required.

<u>Analysis of Present Condition</u>

Before any plan for strengthening any public building can be considered, it will, of course, be necessary in each case to analyze the structure as it was originally designed and constructed. While it may be assumed that in general such buildings, particularly school buildings, are deficient in strength, nevertheless the degree to which the structure fails to meet the standards of construction of new earthquake-resistant buildings must be ascertained. This naturally involves complete analysis of the stresses which would develop in the structure and examination of the material of which the building is built.

Plans for Strengthening

When a building has been found to lack in any particular the strength to resist the forces which act during an earthquake, proper modification of the structure must then be made the basis of special study, unless the building is found to be so weak as to justify its demolition. No general formula or method of attack can be set up, because each structure will, in a large degree, be a separate problem. The same standards of design, however, should be applied as in the case of new buildings constructed to resist an earthquake of the intensity and duration to be anticipated in this region.

The minimum standard of re-design should include an allowance for horizontal forces equal to one-tenth of the superincumbent weight above any level without an increase in unit stresses of more than one-third in excess of those normally used in the design for vertical loads. The same requirements as to bracing in horizontal plances and as to inter-connection of footings should apply in the case of strengthening of existing buildings as for new structures designed to resist earthquake forces.

Personnel

In some instances the technical staff of a public governing body may be able to analyze the condition of existing schools or other public buildings and to design and supervise the work of strengthening these buildings. In most cases, however, a fully qualified staff will not be available and recourse will of necessity be to professional men in private practice.

The situation regarding schools is so serious and the responsibility of each board of education or school trustees is so definite that there should be no delay in providing for the safety of children and others in every school in this entire region. In order that a high degree of competence shall prevail in the analysis of these buildings and in the design of new work for strengthening, each school board should engage the services of only those who are especially qualified to pass upon the safety of the site, to make the structural analysis, and to work out the architectural modifications. In the selection of technical specialists, each school board or other public body should be advised by the representative technical organizations.

Costs

No general estimate can be made of the cost of strengthening existing private buildings as the amount of new construction will vary widely in individual cases. Major buildings, such as fire-proofed skeleton frame office buildings can be made reasonably safe against damage during earthquakes at a smaller proportion of their original cost of construction than buildings of the bearing wall type which have no supporting skeleton frames. However, the latter class of structures represents a much smaller investment in individual cases.

Public buildings, however, may be considered as a group in most communities. Variations in cost of strengthening individual structures will tend to compensate so that a general approximation can properly be made. In rare cases the cost of strengthening school buildings will be less than 10 per cent of the first cost. In most cases, however, an expenditure equal to 15 per cent to 30 per cent of the original cost of these buildings probably will be required in order that the safety of children in the schools can be assured. These estimates, of course, do not apply to buildings which were damaged to a high degree in the earthquake of March 10, 1933. In some instances the cost of strengthening even undamaged buildings will exceed 30 per cent and the decision as to whether to strengthen a building or abandon it must then be made.

For the average urban community it may be assumed that a sum equal to 25 per cent of the original cost of all school buildings will be required directly and indirectly to make these buildings reasonably safe in event of an earthquake. To the actual cost of all new work and reconstruction must be added special costs of investigation and in many cases a large sum for temporary housing of children. While the cost of school buildings in California averages approximately $50 per capita, the investment in such buildings in communities where major structures are general, probably is closer to $60 per capita; consequently it should be anticipated that about $15 per capita may be required to meet the cost of making the schools safe. In the aggregate, the expenditure therefore will be large, but the question should be only how can the necessary funds be provided.

Methods of Financing

All public works must be financed in one of two basic methods, either by direct taxation with payment of costs out of current revenues, or by borrowing the money to be repaid out of future revenues. Under the laws of California, all construction of school buildings, and alterations, repairs, restoring, or rebuilding of any school building, must be by one of these basic methods.

Only in rare cases would it be possible for a complete program of rehabilitation of school buildings to be met out of current tax revenues. While this policy of "pay as you go" is desirable, it would probably involve a large increas in school taxes in any case and in most instances the necessary increase would be in excess of the legal limit.

Consequently, borrowing the money through the issuance of bonds must be faced by most communities. The public which rightfully demands that school buildings shall be made safe, must back their demand with the willingness to bond the community for enough money to carry out the proper program of rehabilitation.

Many school buildings in a number of communities were so seriously damaged in the earthquake of March 10, 1933, that legal restrictions will prevent the issuance of bonds in sufficient amount to rebuild these schools and to strengthen others less seriously damaged. In this connection, a new law has been passed, which will permit the State of California to obtain funds from the Federal Government and to replace or reconstruct public school buildings in such areas. Under this law, the State can then rent these new buildings or reconstructed buildings to such school districts and receive back from the school districts payment over a long period without it being necessary for the school districts to increase their bonded indebtedness.

General financial conditions will dictate that in most instances the necessary financing for school reconstruction should be obtained by the calling of an election by the board of education or the school trustees for submission to the electors of the school district the question of the issuance and sale of bonds. Such a procedure would, of course, place the responsibility for strengthening the schools and making them safe against damage during an earthquake squarely upon the public whose children occupy these schools.

PREVENTION OF CONFLAGRATIONS

In the case of almost every earthquake, many fires are started in buildings damaged by the shock. Fortunately, such fires did not get out of control in any of the earthquakes which have caused partial destruction of buildings in Southern California cities. However, following the earthquake of April 1906 in San Francisco, a conflagration developed which was not under control until the damage from fire was perhaps ten times the damage directly resulting from that earthquake. In Tokyo in 1923, a great fire swept over a large part of the city; the resulting damage to property was far greater than that directly caused by the earthquake, and in the fire tens of thousands of people lost their lives.

An earthquake of the intensity and duration of that which occurred in San Francisco in 1906 may occur at any time at almost any place in this entire region. Unless adequate provisions are made to minimize the damage to buildings, it is a virtual certainty that a large number of fires will develop throughout any community subjected to such a shock. In order that such fires can be brought under control promptly, the water system of the community, the fire fighting equipment, and the organization developed to meet such emergencies must be capable of functioning efficiently and without delay.

Building Construction

It is of primary importance that all new buildings be so designed and constructed as to be capable of withstanding the shock of an earthquake of severe intensity, and it is of equal importance that all existing structures be strengthened so as to have like resistance to such an earthquake. When buildings in the cities of the Pacific Southwest have been made strong enough to withstand earthquake shocks, then the chance of serious fires will be little more than the hazard continually present in any congested area.

Should a fire develop in any building as result of an earthquake, the spread of this fire to other areas can best be prevented by building construction which is fire resistant.

The frames of buildings should be fireproofed by material which will not easily be broken or fractured. Light wells, service shafts, and elevator shafts should be protected by incombustible fire-resistant walls and metal doors. In congested districts, the use of metal sash and wire glass or equivalent substitutes is highly desirable, and it is important that window openings in front of buildings should be protected as well as on the side and in the rear of such buildings. Within such buildings, combustible material should be limited as far as practicable and wire glass rather than plain glass should be used in corridors. Parapet and fire walls intended to limit the spread of fire should, of course, be so built as to prevent their collapse.

Water Supply and Other Utilities

In San Francisco the water system was seriously affected by the earthquake and in many parts of the city water was not available with which to fight fires that developed. This condition was so serious that an elaborate system of duplicate mains and distributing reservoirs has since been provided in that city as insurance.

In Los Angeles, somewhat similar provisions have been made. Furthermore, it is fully recognized that most of the water supplying Los Angeles is brought from Owens Valley through an aqueduct which crosses the San Andreas rift and numerous other faults. While the hazard of interruption is thus present, reserve storage has been provided near the city in sufficient quantity to meet all needs for several months.

In general, every city should be provided with a supply of water from different sources and, where pumping plants are required, duplicate sources of power should be available. In order that no large area might be isolated from all sources of supply, there should be a number of distributing reservoirs so located that each section of the city is in effect supplied from a separate source. In addition, all parts of the system should be interconnected at several places with mains large enough to permit the delivery of water into any area by a number of routes. The entire distribution system should be equipped with valves so located that any broken main could be isolated and service continued through pipe lines around the break.

Interruption to the delivery of gas is liable to occur in event of an earthquake in approximately the same degree that the water system is affected. Electric lines are less subject to damage, except by falling debris. In Southern California both gas and electricity are obtained or could be obtained promptly from a number of different sources, so that there is little liklihood of an interruption longer than that deliberately created in the interest of safety. Immediately following any earthquake which results in damage to buildings, the supply of gas to the affected area should be cut off as a fire prevention measure, and all damaged electric lines should likewise be put out of service until all danger has been removed.

Fire Fighting Equipment:

In every community there is, of course, a fire department equipped to fight fires which occur from time to time. In order that such fire departments may be able to prevent a conflagation following a severe earthquake, all equipment and personnel should be located only in buildings which are especially resistant to fire and earthquake shock. This is of particular importance in the case of fire alarm headquarters and this building should preferable be constructed in the center of a large open area.

Had a number of serious fires developed in Long Beach, a cônflagation might well have followed, for the fire department in that city was seriously handicapped for some time on account of the partial destruction of some of the fire stations and by failure of the fire alarm system.

There should be in each fire district chemical apparatus or motorized water tanks with boosters which could be mobilized quickly in case of failure of any part of the water system. Fvery fire department, except in small cities, should include a corps of men especially skilled in the handling and use of explosives. When the spread of a fire cannot be prevented by ordinary methods, demolition of buildings is required. It has been found that demolition was generally ineffective until directed by those trained for this use of explosives.

Interior fire protection in individual buildings vastly lessens the risk, whether sprinklers are supplied by gravity from elevated water tanks or by pumping from some source other than the water system of the community. In order that this local water supply should be available in case of necessity it is, of course, obvious that all equipment must be provided with safeguards in case of an earthquake and the water tanks must be capable of resisting lateral forces. Chemical estinguishers should be abailable in numbers in every building so as to make possible the immediate control of incipient fores.

Disaster Plan

In Los Angeles and in many other large cities of this country a major disaster plan has been worked out carefully and has been modified from time to time to meet changed conditions. Such a plan, covering not only one city but all neighboring communities, is of the greates importance. Full responsibility for the execution of a definite, carefully organized plan of action should automatically be vested in previously selected authorities and this plan should be understood thoroughly by the staffs of all fire and police departments, and by all others whose cooperation would be advantageous. While, following the earthquake of March 10, the necessity did not arise for putting into execution the major disaster plan, prompt and effective aid was rendered to Long Beach and other communities by the Los Angeles Fire and Police Departments.

Aside from other considerations of city planning, it is desirable that there be many wide streets and large open areas which would aid in the isolation of serious fires.

Summary:

It must be recognized that earthquakes of more than moderate magnitude may occur at any time in this region that a severe conflagation might follow such an earthquake, and that as a result the damage might be increased ten-fold. It is theefore very important that:

(a) Buildings and other structures should be designed and constructed or strengthened so as to be capable of resisting earthquake forces.

(b) Buildings should be made as nearly fireproof as practicable, and that all buildings in congested districts should be fire-resistant to a greater degree than is now required.

(c) Fire departments should be especially equipped and trained to combat a conflagation.

(d) A major disaster plan should be worked out in each area with the same care and high degree of organizat on as the plan which has been developed in Los Angeles under the guidance of the Fire Department.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

All of California and other parts of the Pacific Southwest are in a region of seismic activity. Earthquakes have occurred throughout the entire geological history of this region, and the historical record of two centuries is filled with instances of earthquakes of more than moderate intensity. The geological structure of Southern California is characterized by numerous faults upon which an earthquake may occur at any time. Particularly on the coastal plain where the greatest concentration of population exists, there are large areas of deep alluvium which intensify the shock of an earthquake.

Contrary to popular conception, the hazard of damage by an earthquake is not restricted to a narrow zone along a fault, but is generally uniform. An earthquake of locally destrictive force may occur on any one of the smaller faults close to any community, or a slip of major proportions may take place on a more distant fault with equally disastrous effect. There can be no doubt regarding the necessity of protection in this area against an earthquake of the intensity and duration of that which occurred in the San Francisco region in 1906.

In Long Beach and neighboring communities there was far too much damage as a result of that earthquake of moderate intensity. The lessons which should have been fixed indelibly in the minds of all by the destruction to buildings and other works in San Francisco in 1906, in Inglewood in 1920, in Santa Barbara in 1925, and in other communities in California and else where in the world, had been disregarded. Almost no buildings in this region had been designed to resist earthquake forces, and the poor quality of construction in many cases contributed to the destruction. Over one hundred lives were lost by the collapse of walls, parapets, and by other falling debris, substantially all of which should and could have been prevented.

Damage to schools, which children are required by law to attend, was widespread, and it was only by chance that thousands of children were not killed. A great many schools in this region which were undamaged in that locally destructive earthquake are little better than which suffered so severely. No one can question the imperative necessity of prompt and effective correction of the weakness prevalent in the schools.

During an earthquake all structures are subjected to shocks from all directions and of varying intensities. Experience in cities where severe earthquakes have occurred has let to the conclusion that reasonable protection against earthquakes can be obtained, provided that the building or other structure is properly designed and constructed. In the design of buildings to resist an earthquake of the intensity and duration to be anticipated in this region, horizontal forces equal to one-tenth of the superincumbent weight above each level must be assumed as being applied in any direction. While more rigid standards have been adopted in regions of greater seismic hazard, it is believed that a momentary increase of one-third in the unit stress of materials is justified.

Compared to the large number of buildings which now exist in this metropolitan center and in other communities throughout the Pacific Southwest, relatively few new buildings will be constructed during the next ten years; consequently the necessity for strengthening existing buildings is more important even than a change in the standards for new buildings. Insofar as the police power of the State will permit, all privately owned existing buildings should be made earthquake resistant. Strengthening of public buildings, however, is subject to the will of the people, and there should be no delay in making these buildings, particularly school buildings, safe.

It is recognized that strengthening of all school buildings so that they will be fully capable of resisting the force of an earthquake of greater intensity and duration that that which occurred in Long Beach will require the expenditure of large sums of money. The question, however, should be only that of how this money can be best and most quickly provided.

While there have been a number of earthquakes which have not been followed by conflagation, the damage by fire in San Francisco was perhaps ten times the damage which resulted directly from the earthquake, and in Tokyo the conflagation which followed the earthquake of 1923 not only did tremendous damage to property, but caused the loss of tens of thousands of lives. Fires are not liable to start in buildings which are not damaged, and consequently strengthening of buildings to resist earthquake shock is a primarly factor in the prevention of conflagations. Proper fire protection of buildings, particularly in congested areas, is necessary to prevent the spread of fires. Water systems must be protected from damage as far as practicable, and other means of combating fire must be provided.

At some time in the future an earthquake of major intensity will occur in this region, and unless existing evils are corrected by adequate protection against earthquakes, disaster must follow. A carefully organized plan of control, under centralized authority, is imperative to minimize that disaster.

The manifest advantages that will accrue to all communities throughout California and other parts of the Pacific Southwest by providing adequate protection against earthquakes can be realized only by sacrifice on the part of those now here.