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EARTHQUAKE RISK AND ITS ABATEMENT IN CALIFORNIA

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LONG experience has made it certain that the occurrence of earthquakes in and near California, and the attendant risk that there is from this cause, are matters not well understood by a vast majority of people both inside the state and beyond its borders. For the most part non-residents overestimate and residents underestimate the risk here from earth shocks. In both respects so general a want of understanding is disadvantageous to the region. From every point of view the situation calls for clarification.

Manifestly there is some risk—of death, injury and loss of property—in every actively seismic region where very small earthquakes are frequent, somewhat larger ones numerous, with the occurrence of shocks of small destructiveness every year or two on the average, and moderate, large and great earthquakes at longer and longer intervals. California is such a region.[1] How great is this risk, and how is it spread? What can be done to abate it?

Although the following discussion necessarily deals specifically with California and the immediately neighboring region, the general conclusions reached apply also to seismic regions elsewhere, including some other districts in the United States.

[1] See "Destructive and Near-destructive Earthquakes in California and Western Nevada," U. S. Coast and Geodetic Survey, Special Publication No. 191.

HISTORICAL RECORD

The historical record of earthquakes in California and adjoining territory does not begin until the spring of 1769. Since earthquakes in a seismic region are recurrent geologic phenomena, and so should properly be considered in terms of the geologic time-scale—a scale which can not be divided precisely or appreciated, in brief units of scores or even hundreds of years—the interval since 1769 is far too short to permit any but tentative conclusions to be drawn regarding the true degree of seismicity of the region and the corresponding risk from this. However, the record for this interval in the California region can be compared with those for the same interval, or similar ones, in other regions. On such a basis, possibly an insufficient one, the risk in California appears significantly less than in many other seismic lands such as Chile, Italy, Asia Minor and Japan. Moreover, on this same basis, the risk in and near California is less, and less prevalent—especially with regard to continually impending danger in all places—than appears to be the wide-spread apprehension of large numbers of non-residents, as evidenced by innumerable letters, inquiries, conversations, press comments, etc., emanating from all parts of the country over an interval of many years. Though earthquakes can not be predicted, and a significant shock may occur at any time at some place within the region, as a matter of fact such shocks are by no means frequent in any one district and no such general apprehension is warranted either by the recorded history of shocks or by the probability based on geological considerations. No one in California lives in continual dread or fear of earth shaking.

PUBLIC INCOGNIZANCE OF RISK

On the other hand, there is some degree of risk, and the geographic spread of this risk over the region is wider than local residents generally realize. Risk is present in many places where people give no heed to it. There are several reasons for this. The historical record of shocks, such as it is, has not been readily available to most residents, and perhaps not very interesting to them. The great shocks, three in number, have occurred in different districts and at considerable intervals—in 1857, 1872 and 1906. The other large destructive shocks, about ten in number, have been separated fairly widely both in time and in place of occurrence, and this is also true in general of the thirty or so large to moderate earthquakes of more local character. Even shocks of small destructive force, though numerous in the region as a whole, usually have not affected any given small districts more than once in an interval of several years; and often they have been so small that the damage done has been very narrowly limited and sometimes of little moment. In numerous localities people have lived for many years without suffering any damage whatever from earthquakes. The non-destructive felt shocks (excluding aftershocks following strong earthquakes) are not often very numerous in a given place, and frequently they give rise only to a thrill, or hardly that. The exceedingly numerous unfelt shocks registered by seismographs are known to but few who are not students of earthquake occurrence. Memories of strong shaking fade with time, or at least general awareness of such action dies away. The influx of population in the last twenty to forty years has been very large, on the whole increasing rapidly with the years, so that a very considerable part of the people now resident in the California region, including the younger generation, has practically no knowledge of the earthquake record nor any adequate conception of the frequency or spread of shocks. These things, with others, account for the fact that residents in many localities do not realize their risk. For example, quite genuinely a very great part of the people affected by strong shaking in the Long Beach earthquake in March, 1933, were surprised at the occurrence of a destructive local shock centering so close to the thickly settled Los Angeles plain—though persons acquainted with the record well know of the earlier occurrence of even greater shocks in the same district. The public simply does not know or appreciate the wide spread of such risk as there is—a risk which usually can be made negligible by suitable precautions.

RELATION OF EARTHQUAKES TO FAULTS

In a large number of cases the central areas of the important shocks have been intimately associated with geologic faults, and in some with the fresh offset slipping of these faults right up to the surface. In many cases this is known without any doubt whatever, and in many more any doubt that there may be is so slight as to be negligible practically, while in many others this association with faults is indicated very strongly, though the information in the historical record, not assembled by scientific men, may be insufficient to demonstrate such a relationship conclusively. It is generally held that most earthquakes are caused by the sudden release of elastic strain when this becomes greater than the strength of the rock, or more commonly of the cohesion or adhesion and friction in a zone of faulting previously broken and displaced—with new or renewed slipping, vibration and the radiation of elastic waves from the place of rupture, the source or origin of the shaking. Our knowledge on this point is not strictly conclusive, but this is the best judgment of qualified men of science, and this view has been widely accepted by well-informed members of the public. There is, however, an imperfect general

understanding of it and its practical meaning. It appears to be thought by almost all laymen that danger from shaking is confined to the very close vicinity of the fault source. Thus it happens that there are many inquiries from more far-seeing individuals and corporations regarding the location and course of faults, in the desire to avoid their immediate neighorhood in the erection or rental of residences or other buildings or works of construction. Wise as this attitude is in many circumstances, it is not sufficiently understood that close proximity to an active fault—which will sometime give rise to a significant earthquake—is only one of the factors, and usually not the most important one, in the risk or danger from shock occurrence. Such risk is far more widely spread. Of course, when the fault slipping extends up to the very surface of the ground any structure which is built astride the crack or cracks along which displacement takes place is bound to be damaged or destroyed unless it is constructed so strongly that it can ride along on its foundations on one side of the crack, leaving behind its foundations on the other—even in such a case extensive repairs will almost always be required, and any occupants will be subjected to great hazard and a very terrifying experience. Usually, however, the fault slipping does not extend up to the surface. And often, perhaps usually, the rocking and shaking is not so violent at the very *innermost* part of the central area, the so-called epicenter or epicentral tract, as at some *small* distance away from it. Thorough discussion of this relationship would require much space. Brief discussion may not be clear to all readers.

EARTHQUAKE WAVE-MOTION

However, this relationship appears to be due in part to the angle of emergence of the shock waves—strictly vertical vibration being less destructive to works of construction, built to withstand vertical stresses, than inclined or horizontal vibration; but even more to the *apparent* fact, which has strong theoretical support, that the *surface waves* (which seem usually to be far more destructive than the *elastic body waves* which first come up to the surface from the deep source of the shock) are generated and developed more effectively at *small* distances from the epicenter than at the epicenter itself. The size, shape and geographic location of the areas where these surface waves may be most effectively developed will depend not only upon the depth of the origin but also upon the mechanism or way of slipping of the fault. About this latter relationship we do not know very much as yet.

Of these surface waves there are surely two, probably three and possibly more kinds. There are two *elastic* surface waves, which have larger amplitudes of vibration than the original body waves. One of these vibrates parallel to the surface and at right angles to lines along the surface radiating from the epicenter. The other vibrates in elliptical paths in the vertical planes which radiate from the epicenter. Of these the second should be the more destructive.

Further, there may be quasi-elastic, quasi-gravity waves of still larger amplitude. There are countless reports of *visible* surface waves which, if real, must be very destructive, since the amplitudes are described as large (up to two or more feet in the vertical) and the wave-lengths as short (six to twenty feet, more or less), the ground surface presenting a waving appearance like the disturbed surface of a body of water. We know positively that some of these reports are mistaken. It seems probable that most, if not all, are due to unconscious oscillatory disturbances of balance, perhaps to unconscious movements of the eyes, or possibly to a purely optical effect, and that such reported waves did not actually occur in the ground. But it may be possible that they are sometimes real and if so they must be very destructive.

Further still, there is little or no doubt that true gravity waves are set up in loose, wet ground, sometimes with very large amplitudes and very destructive potentiality. Also in such bad ground sometimes permanent wave-like deformation of the surface is observed accompanied by marked destructive effects. These phenomena are observed out to some considerable distance from the fault or epicenter depending on the size and strength of the earthquake.

There is also the possibility of the additive or subtractive combination of all these wave motions, body and surface alike, especially in a shock of prolonged duration, increasing the violence at one place and decreasing it at another. The resultant effect, as a whole, may be very complex.

EFFECT OF FOUNDATION GROUND

From the point of view of risk, far more important than this complexity of wave-motion in itself, or distance from the source (within a small range), is the nature of the ground at the surface. The energy or power of the shock, of course, is carried outward from the source by the several wave-motions, but the *effect* produced at the surface is *very greatly* different on different kinds of ground. Over and over and over again it has been observed that destructive effects are less on hard rock than on soft, less on soft rock than on alluvium or sand, greatest on marshy or filled ground, or "made land," especially when the latter are highly charged with water. There are innumerable examples of this, and exceptions to it are very few and of uncertain nature. The effects in San Francisco in 1906 afforded striking and detailed demonstration of it. There was far greater contrast between the damage

caused on the rocky summit of Telegraph Hill and that on the wet "made land" near the Ferry Building—places distant about ten miles from the fault source and less than a mile from each other—than there was on rock or firm ground over a range of twenty miles or more eastward from the Cliff House (which stood some four miles east from the fault). All over the area of the city the damage was far more closely related to the kind of ground at the surface than it was to the distance from the origin of the shaking. It is true, of course, that when *large ranges of distance from the earthquake source* are considered, near localities are more severely affected than far ones; but very bad ground not too distant is a much worse foundation than very good ground quite close at hand. *These facts can not be emphasized too strongly.*

Geographic Spread of Risk

It is for the reasons given above that such risk as exists is spread far more widely than is generally known or appreciated. Further, active faults are more numerous than is generally known, and many of them are not shown clearly at the surface. Some probably are yet unrecognized, for some have become known only within the last ten to twenty years. A given locality may be safely distant from one potential source, questionably near another and dangerously close to a third. Not all such sources are equally dangerous, but close proximity to the source of a small or moderate destructive shock may be more dangerous than moderate proximity to the source of a really great shock, foundation ground and building structures being the same in both cases. Close proximity of inhabited places to the origins of earthquakes like those which affected Santa Barbara in 1925 and Long Beach and numerous neighboring cities and towns in 1933, shocks of only moderately large total energy which, nevertheless, were destructive over comparatively small areas and of fairly high strength or intensity locally, show this clearly. Had the Long Beach shock been one of large total energy a great disaster would have resulted.

The wide spread of what risk there is from earth shaking in the California region is not a matter of hypothesis—it is a fact proved by the historical record. Since the earliest shock recorded in 1769, more than two hundred destructive and near-destructive earthquakes have occurred in and near California, including the forty-odd great, large and moderate shocks previously referred to. (Such shocks as the Santa Barbara and Long Beach earthquakes belong in the group of about 30 moderately strong local shocks).

For many years after 1769 inhabited places in California were few, small and mostly separated by large distances. With the gold rush in 1849 people began to come in much larger numbers, but only within the last two or three decades has the population influx been really large and the number of cities, towns and villages become numerous and closely spaced. This applies with special force to the southern part of the state. Even to this day a great part of the area of California and adjoining territory is practically uninhabited—desert, mountain, forest, range and scantily peopled ranch land. Notwithstanding all this the inhabited places where damage from shock has been reported, at one time or another from 1769 onward, are so numerous and so widely and generally spread throughout the state that hardly any settled district can be considered free from some risk. This remains true, even when the comparatively large areas violently or strongly shaken during the dozen or so greater shocks are disregarded. Moreover, such a historical record as we have, under the circumstances outlined above, shows us only the *absolute minimum* of the geographic spread of risk, for the time interval is very short, approximately 170 years, population for a long time was small and sparsely distributed, and the body of information is very, very incomplete. Many places now inhabited must have been shaken strongly in the earlier years before their settlement, as well as places still unsettled, by shocks of which we have no adequate record, or none at all. If a map could be prepared to show all places in which shaking strong enough to damage structures has occurred since 1769 (if structures had been present like those which have been damaged from time to time in the past) a very large part, perhaps almost all, of California and western Nevada would be included.

Geographic Variation in Risk

Although such risk as there is is general and widespread it is not everywhere the same. Between the extremes of greatest risk and least the margin may be wide, and probably it is; but it is extremely difficult with present knowledge to appraise the degree of risk for this, that or the other locality or site. No one knows where or when destructive shocks will originate, nor how large or strong they will be. Consequently no one can say when a particular locality or site will be shaken, nor how strongly. We do know some faults, such as the San Andreas, along parts of which strong earthquakes must originate in the future, as in the past; but we do not know when, nor which part will be affected on any particular occasion, nor how strongly. Other faults are under suspicion. Still others probably exist which are quite unknown to us now.

The important thing which we do know is that "made land" and fills, especially when water-soaked, are certainly dangerous in some localities and probably everywhere; that loose water-charged natural ground is more dangerous than dry compact ground; that soft

rock is less dangerous, and hard rock least dangerous of all. A well-designed and well-built structure on a good rock foundation near the source of a strong earthquake is, in general, in much less danger than a poorly designed, poorly built structure on bad foundation ground considerably more distant from the source. Thus, although there is some risk almost everywhere in the region—on the basis of the historical record the average risk is not great, nor danger always impending at all places. Such as it is, the risk can be greatly reduced if the facts are recognized and suitable precautions taken. On the other hand, if the facts go unrecognized or are disregarded, sooner or later earthquakes will take their toll. For example, the San Francisco shock occurred in 1906; in earlier years, as a matter of history, the Los Angeles plain district had been shaken strongly on several occasions. This was forgotten or disregarded. A great majority of the buildings and structures damaged there by the Long Beach earthquake in 1933 had been built later than 1906. Had the lessons of 1906 been applied to this recent building in the cities and towns of the Los Angeles plain very little damage need have occurred, with little or no loss of life and comparatively few injuries.

ABATEMENT OF RISK

Earthquakes can not be prevented, precipitated nor controlled—nor predicted except in a broad general way. The population in California is certain to increase greatly, and more and more cities, towns and villages will come into existence, and most existing centers will grow. Even the rural districts will become much more occupied by people. It follows that the thing to do is to build well and suitably on good ground wherever possible and to take special and adequate precautions in all cases where it appears necessary to build on doubtful or actually bad ground. (There is some ground, like the narrow surface zone of the San Andreas fault, where no important buildings should be built at all). At the present time this applies to all parts of the whole region, even though in the far distant future it may gradually become certain that some districts are, practically speaking, really safe from destructive shaking.

Unfortunately, there is one aspect of the risk as it now exists that will require time for abatement—even if the public should now become thoroughly cognizant of danger from shocks and remain always alert. During the rapid growth of population in recent years, at an ever increasing pace, all sorts of buildings and other works of construction have been built in great number on all kinds of foundation ground. Some construction, good from the earthquake point of view, is on good ground, some on bad ground, some on ground of intermediate quality. Similar statements hold for construction of intermediate, and of bad design and workmanship. Some of this construction can be greatly strengthened at low or moderate cost; some can not. Immediate removal and replacement of all risky construction is a physical and economic impossibility. In the course of time all of it will be removed and most of it replaced. If, beginning now, all replacement is of construction suitable to resist earthquake shaking—gradually the risk will diminish toward a minimum. While we can hardly expect the maximum rate of abatement of risk in this way to be realized, important improvement in this regard can certainly be achieved. It should be stated that a beginning has been made and some progress achieved in the improvement of building codes and legal requirements for the construction of schools and other public buildings, but what is really required is general public realization and demand for suitable design and construction under all circumstances.

For the future the only safe procedure is to design and build well on good ground and with especial precaution on doubtful ground. There is still much to learn as to the better and best ways to design and construct. Studies to this end must go forward steadily even though a good deal is known now.

VALUE OF INSURANCE

Some protection against property loss and personal injury—and provision for dependents and heirs in case of death—can be obtained from insurance, but at best this recognizes risk of destructive effects, and these can be prevented in large measure though not eliminated completely by taking into account the wide spread of the danger from shaking and everywhere building well with this in mind. Even from the point of view of insurance this is the best procedure by far, for insurance rates will in time become much lower on good ground and good construction. The best insurance is suitably good construction, and the added cost on new structures is only a small percentage of the total investment. For a long time to come, however, some recourse to insurance policies will be judged necessary or desirable in a great many cases. So long as bad constructional conditions, taking foundation ground into account, remain existent individuals and corporations can protect themselves in considerable measure by selection in the purchase or rental of property and by recourse to insurance. The ideal, however, is the general lessening of danger by good new construction and the strengthening or replacement of old weak structures at the quickest practicable rate. From every unselfish point of view the enlightenment of the public regarding the true spread of risk and how to combat it is emphatically desirable.

MISLEADING STATISTICS

Present statistics, resting on far too slight a basis, indicate the risk to life and limb in California to be small—ridiculously small, less than the risk from common trivial diseases. But this is not a true picture. It is due to the past occurrence of the small number of greater shocks at fortunate times of day. Had the Long Beach earthquake, or that at Santa Barbara, for example, to say nothing of the San Francisco shock, occurred at unfavorable hours the statistical story would be a very different one. Energetic shocks will not always continue to occur at most favorable times of day. Some time one will happen when people are in the streets, or in theaters, churches, schools, etc. Once again the answer is the same. If all buildings are well built the risk will be small. Even panic will be reduced. If bad or unsuitable construction is general disaster or catastrophe will result. The moral is—design and build well on good ground, and in case of doubt insure. There is no other way to security.

To conclude—necessarily the greater part of this article deals with the risk that there is, its geographic spread over the region, and what can be done to lessen it. It is very desirable to fix the attention of residents upon the actual situation and to persuade them to courses of procedure which will ensure greater and greater safety. On the other hand, as stated in the beginning, the risk from earthquake occurrence in the California region, though more general and widespread than most residents realize, is nevertheless much smaller than most non-residents and some local people commonly think—far less than the risk in many other parts of the country from hurricanes, floods, tornadoes and other natural causes of disaster. In justice to California and neighboring territory emphasis must be placed upon these facts. It would be unfair to the region if efforts to secure in it safe building and constructional procedure should be construed as a warning of danger of great magnitude constantly impending at all places. While no one can foretell the future of earthquake occurrence in any practical way, the historical record since its beginning in 1769 gives no warrant for such alarm or serious apprehension. All that is warranted is recognition that earthquakes will continue to occur in the future as they have occurred in the past and that safety from the shaking requires good judgment in the selection of sites and the adoption of suitable resistant methods of construction.

THE ROLE OF AEROBIC PHOSPHORYLATION IN THE PASTEUR EFFECT

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A DECREASE in rate of carbohydrate utilization upon admission of oxygen is characteristic of many tissues. The various mechanisms which have been proposed for this Pasteur effect have been adequately reviewed by Burk.[1] It is the purpose of this note to call attention to a possible mechanism which does not appear to have been specifically mentioned elsewhere.

This mechanism is, in short, the following: If both aerobic and anaerobic carbohydrate breakdown are necessarily phosphorylative processes, inorganic phosphate and a phosphate acceptor are essential reactants; in their absence neither glycolysis nor oxidation could proceed. The Pasteur effect could then be regarded as the cessation or reversal of glycolysis which takes place when concentrations of inorganic phosphate and phosphate acceptors become low because of the phosphorylative oxidations which occur in the presence of oxygen. The necessary conditions for the operation of this mechanism are:

(1) The glycolysis reactions must be readily reversible.

(2) Phosphorylation (esterification of inorganic phosphate) must be an essential step in both the glycolytic and the oxidative processes.

(3) The oxidative phosphorylation reactions must be capable of reducing the inorganic phosphate (and phosphate acceptor) concentration to a level lower than that attained at glycolytic equilibrium. That is, oxidative phosphorylation must be possible at inorganic phosphate concentrations too low to permit glycolytic phosphorylation.

(4) The number of molecules of phosphoric acid esterified when one molecule of carbohydrate is oxidized must be greater than the number esterified when one carbohydrate molecule is glycolized.

(5) The same reservoirs of phosphate ester, inorganic phosphate and phosphate acceptor must be available to both the glycolytic and the oxidative enzyme systems.

An adequate discussion of the likelihood that these conditions are actually fulfilled in isolated muscle can not be given here. Each point can be given only the briefest consideration.

(1) The glycolysis reaction may be summarized by the following equation:

[1] D. Burk, *Cold Spring Harbor Symposia on Quantitative Biology,* 7: 420, 1939.