IX. THE ROLE OF SEISMOLOGY IN LAND DEVELOPMENT AND TOWN PLANNING

9.1 Introduction

It was about 1920, when standards for building in earthquake areas first appeared, that seismology, from being a purely descriptive science, became one of the main branches of research on the prevention of natural disasters. At first, such prevention centred solely on the design of structures. Efforts were confined to making buildings stronger in areas where earthquakes had caused damage. It was only later that more general co-ordination of prevention and rationalization of land development itself became matters of policy. The recent past provides a few examples, however: the planning of the virgin lands in Mexico and of the area round Boston was carried out on the basis of a specific policy which included earthquake vulnerability among the parameters selected. Another example is the choice of sites for nuclear power stations or other works involving large investments and a high potential risk for the population.

In co-ordinating prevention, it is important to take into account, besides earthquakes, all other natural phenomena such as floods, drought, landslides, avalanches, tornadoes, hurricanes, etc. Although these phenomena have long been the subject of extensive research, it is only in the last ten years or so that attempts have been made to compare their potential dangers on the basis of uniform statistics.

Natural disaster risks can be introduced as restrictive parameters in work on physical planning, that is to say, on the allocation of land for different activities: agriculture, urban or industrial development, etc.

If there are no data on the risks or if they are not taken into account, there is a danger that new urban centres will be established - or high-cost installations built - without any preventive measures. There are many cases in which villages destroyed by earthquakes have been rebuilt on the same site without any examination of the possible alternatives, but simply by reason of various political and economic pressures.

In the western world, it is only recently that any attempt has been made to balance the different pressures on physical planning, while at the same time taking the risks of natural disasters into account. In this context it should be noted that it is important to weight the different parameters appropriately before using them for planning purposes.

Thus, on the basis of seismic data alone, it would have been possible to check the development of towns (like some in California and New Zealand) which, apart from their obvious vulnerability to earthquakes, offered prospects for development free from any other danger.

Uniform criteria for assessing the risks of different natural disasters have not yet been simply defined. On the other hand, although the time when a natural disaster is likely to occur cannot be reliably predicted, it is at least possible to take appropriate measures at the most exposed places. This policy may now go as far as the formulation of proposals for diversifying investments according to the impact of different kinds of natural disaster on them. For example, investment in agriculture may be given preference over investment in urban development where, other parameters being equal, the earthquake risk is greatest. This kind of measure for the prevention of natural disasters should be given priority, even over earthquake protection for buildings.

The solution would therefore be to establish in the planning process a number of restraining criteria for land development and housing, arrived at by making a weighted evaluation of several factors linked with a given risk (intensity, frequency, vulnerability of certain structures). An undertaking of this kind has good chances of success if there is close collaboration between economists, sociologists and politicians, on the one hand, and seismologists, meteorologists and geologists on the other.

Reverting to seismology and the kind of activity on which earthquakes have the greatest effect, namely civil engineering, it is important to point out at once that, in theory, it should not be asserted that one particular site is more dangerous than any other in an absolute sense, since the degree of danger also depends on the type of construction.

The vulnerability of a very high building will not be the same as that of an extremely rigid one, even though the absolute risk is the same at a given point. We can, however, define one site as being more dangerous than another independently of the type of construction. This is important from the standpoint of the methodology being developed, which provides for separation of the purely physical aspect of the characteristics of the place considered from the civil engineering aspect for the purpose of determining optimum criteria for protection and for prevention of disasters.

In the light of these considerations, the present section on the role of seismology in physical development planning will be arranged as follows:

1 We shall first describe a technique for "macrozoning", i.e. large scale delimitation of seismic zones. It must be pointed out at once that this expression covers neither the study of the influence of local pedological conditions, which is examined when delimiting seismic microzones, nor the study of civil engineering problems relating to the interaction between structures and the soil on which they are built.
   In principle, the delimitation of seismic zones serves mainly for making one or more maps on which the zones are distinguished according to the foreseeable intensity of future earthquakes. Since these maps are made for practical purposes, their content varies according to requirements and the information available. At present, the maps which accompany official building regulations usually only show the territory divided into two or three categories corresponding to intensities VIII, IX and X on the Mercalli scale.

2 We shall then describe the techniques most frequently used for microzoning, i.e. the subdivision of a small area whose general seismic activity is known from previous analysis, in order to take account of the considerable influence of geological conditions and the state of the subsoil on seismic effects at a given site.

The nature of the terrain may be significant in two ways: first, instability of the ground can lead to permanent movements of the surface, which cause distortion of the structures built on it; secondly, earth movement accelerations, which depend on local conditions, affect the inertia forces to which buildings are subjected.

The techniques used make it possible to draw maps showing earthquake risks in varying degrees of detail. These maps can then be used to calculate the horizontal forces to be taken into consideration when designing a structure which will need to withstand earthquake shocks of a given intensity.

The more general problem of physical planning calls for the establishment of criteria by which the date of seismic zone maps can be translated into economic terms. In other words, for each activity to be planned (agriculture, urban or industrial building) it is necessary to calculate the additional cost resulting from its location in a seismic zone. This additional cost includes the amount of damage expected, since for every building there will always be a small but not negligible probability of damage, and a still smaller but not zero probability of collapse. We shall consider this aspect in chapter X, confining the examination of additional costs to building. The methodology described can nevertheless also be applied to other activities.

These additional costs provide a common denominator by which the economic implications of different types of risk can be compared.

9.2 The technique of macrozoning

This section deals with the application of techniques for large-scale delimitation of seismic zones, and is based on the example of the Po Valley in northern Italy, where it will be assumed that it is planned to build a nuclear power station. A building of this kind, like a dam or a plant producing toxic substances, must be guaranteed to be leak-proof even under the severest load conditions and, in particular, under the action of the most violent earthquake.

Seismology, as a science, is less than a century old; it dates from 1879, when Milne invented the first seismograph.

These facts are not without significance. Since the seismic activity of a region can have been studied for only a few decades, it is essential in examining the main seismic characteristics of a zone to rely on historical observations going back as far as possible. In the preceding chapters it was concluded that the studies should cover a period of 1,000 years.

In the specific case of the Po Valley, the information comes from the history of Italy in general, as well as from local chronicles. In addition to these historical data, regional geophysical data must be considered. The generally accepted procedure for correlating these two series of data is that specified by the Atomic Energy Commission for nuclear plants. It comprises the following operations:

1/ zones with distinctly similar geotectonic characteristics are identified around the site considered ;

2/ in these zones, and particularly in the zone containing the proposed site, the main geotectonic structures in which earthquakes are likely to occur are then identified (see Fig. 9-1);

3/ for each geotectonic structure, the probable maximum intensity of an earthquake caused by the existing faults is calculated. This calculation is based on certain criteria such as the length of the fault. It must nevertheless be noted that some recent earthquakes have had greater intensities than those predicted from the correlation of fault length and intensity. Some

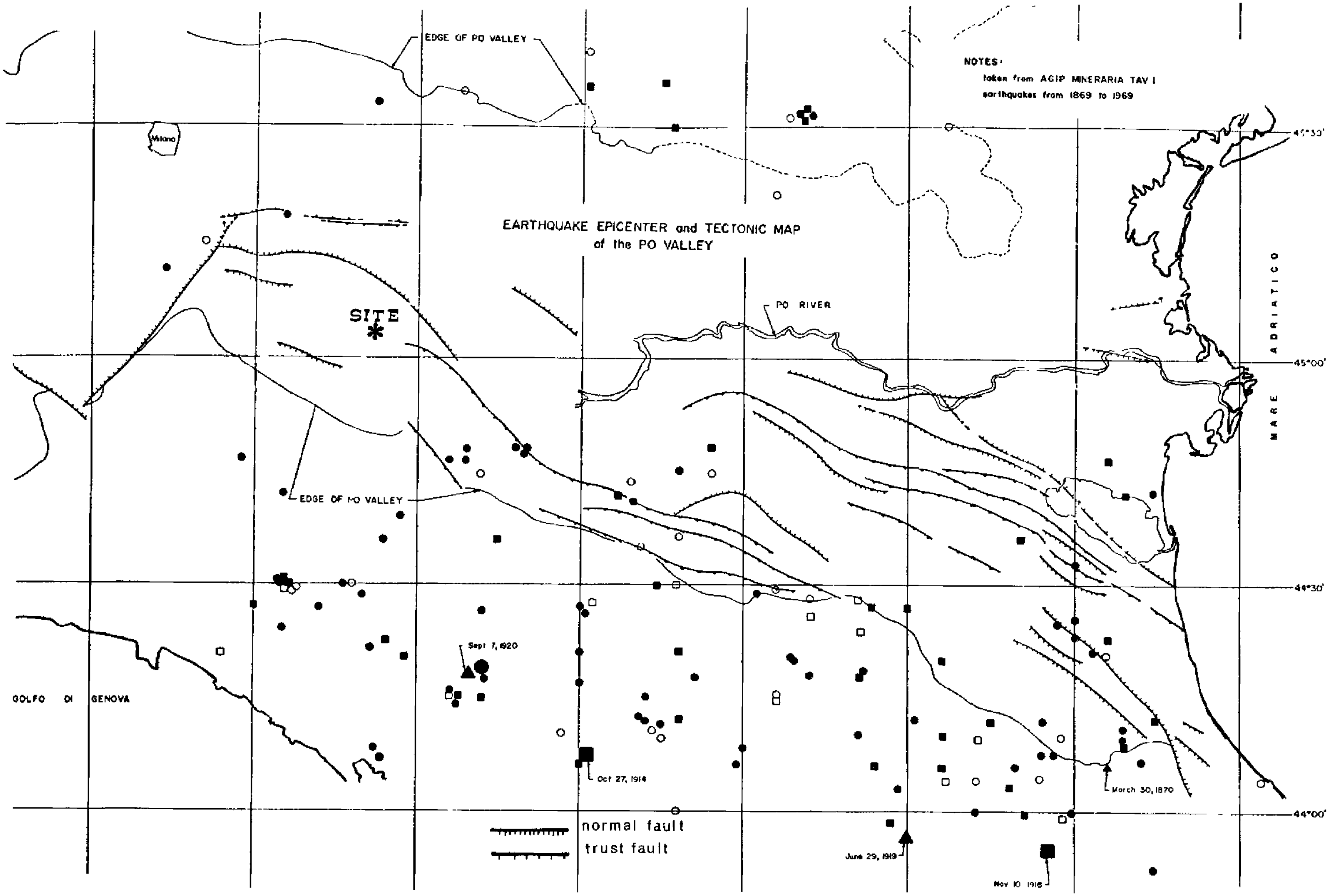

Fig. 9-1 : Map of epicentres and main geotectonic structures of the Po Valley.

caution should therefore be exercised in drawing conclusions of this kind;

4/ the strongest earthquake which cannot be associated with any of the seismotectonic structures previously identified is then determined for each zone. In doing so, account is taken of all earthquakes not clearly on the line of a known active fault in the zone considered;

5/ the procedure is then as follows:

a) it is assumed that the strongest earthquake thus assigned to each tectonic structure may occur at the nearest point on that structure to the site considered;

b) it is further assumed that the strongest earthquake in the zone containing the site may occur in the immediate vicinity of the site;

c) earthquakes having their origin in adjacent zones, which cannot be associated with any of the tectonic structures identified, are automatically assumed to originate on the border of the zone, at a point as close as possible to the site considered.

In practice, there are certain difficulties in applying this technique. With regard to historical data, it must be noted that determination of the isoseismals, i.e. the contour lines of zones which sustained shocks of a given intensity (see Fig. 4-1), is a matter of some uncertainty. For it is difficult to obtain reliable data, especially for very old events. Reference should also be made to Fig. 4-2, which shows the dispersion of earthquake effects according to the type of ground.

It should also be noted that only a few countries possess information on events in the distant past. Such information does exist in Europe, where seismologists began over a century ago to collect and classify information on the effects of earthquakes recorded since ancient times in the archives of monasteries and by the chroniclers of different towns, etc. For Italy, the historian Baratta has made an extensive catalogue of the main events in that country over a period of about 2,000 years. The data he has collected are presented critically and thus show a satisfactory degree of homogeneity. In the case of the Po Valley, for example, the data available relate to 500 different events.

This information, together with the original annals, served as the basis for a recent publication by Vit Karnik covering the whole of Europe and the Mediterranean region, prepared in accordance with the recommendations of the European Committee on Seismology.

The first volume published by Vit Karnik covers the period 1901-1955, and the second volume 1801 - 1900.

The various European national institutes of geophysics are continually making seismic studies of this kind, consisting in a detailed analysis of the events which occurred in each country.

In the case of seismotectonic data, one of the difficulties encountered in identifying the main faults is that of classifying them as active and non-active. In an enquiry covering an area as extensive as the Po Valley, i.e. nearly 80,000 km2, secondary faults which are ramifications of the main faults may often be overlooked.

These difficulties may be overcome, however, thanks to sound statistical interpretation and the fact that the historical and tectonic data are complementary. For seismotectonics make it possible to delimit more accurately the zones which have sustained damage of a certain intensity and to obtain information even where there are no historical data, either because of the absence of local chronicles or because there were no significant buildings to indicate the intensity of the earthquake.

With reference to the results, when only the historical data are taken into consideration (Fig. 9-2, 9-3, 9-4), it is found that the map of maximum intensity (Imax) made by this procedure coincides with the maps of observed maximum intensity for the same region. Now the results of the study mentioned above should clearly lead to the adoption for each site of an assumed maximum intensity greater than the observed maximum intensity. The validity of the results of such a study can be further verified as follows:

1) In theory, Imax should not vary if it is calculated without taking account of the most recent macroseismic data, in other words, to give an order of magnitude, when 10 per cent of the seismic events catalogued are not included in the enquiry. For in this case, the map only reflects future seismic activity and the addition of a new event makes no substantial difference.

2) Moreover, the Imax map should not differ appreciably from the map of observed intensity. To give an order of magnitude, an average difference of one degree of intensity may be considered acceptable.

The first condition is regarded as a test of the completeness of the seismotectonic data, whereas the second, more difficult to achieve, indicates an historical enquiry already significant in itself.

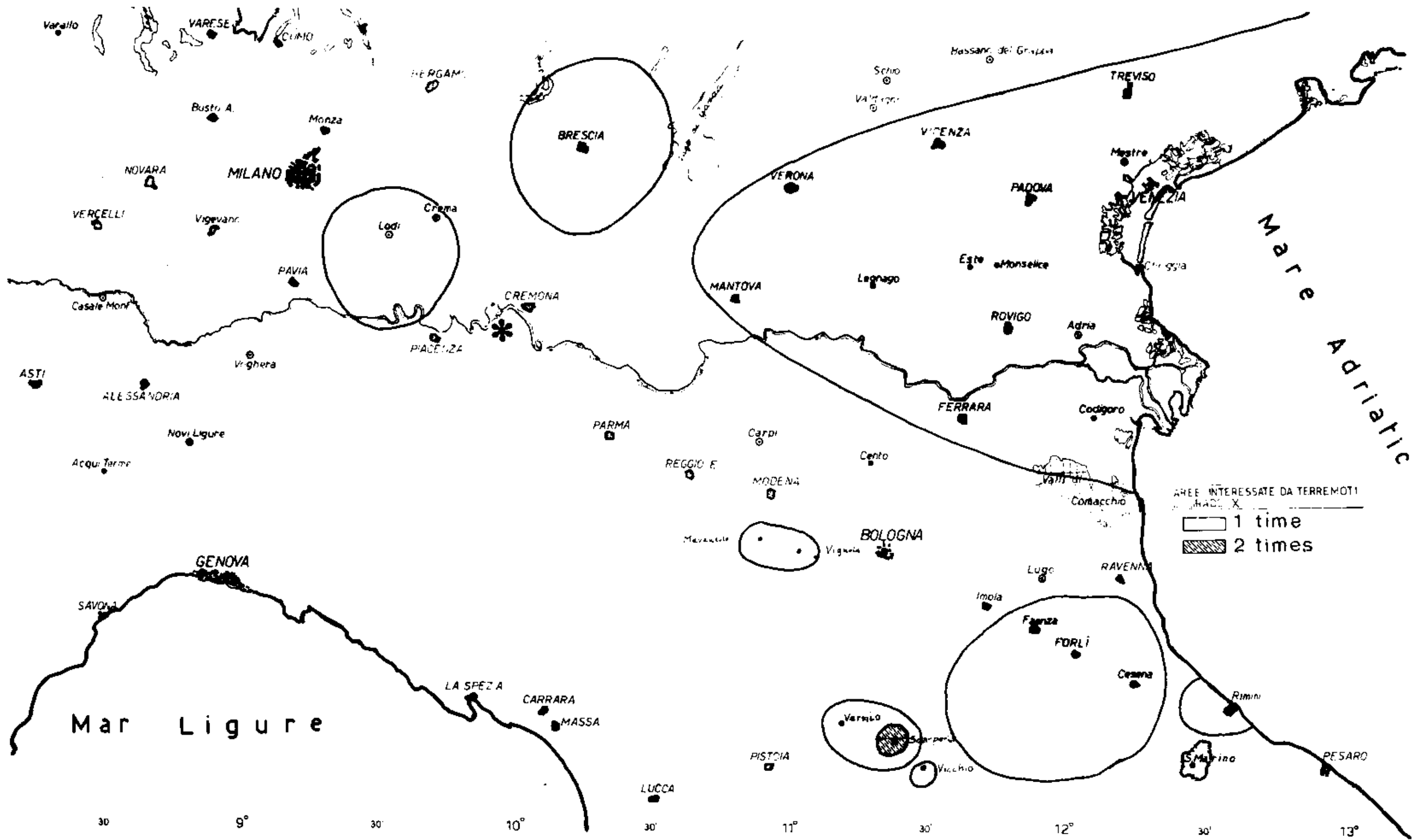

Fig. 9-2: Zones subject to earthquakes of intensity X.

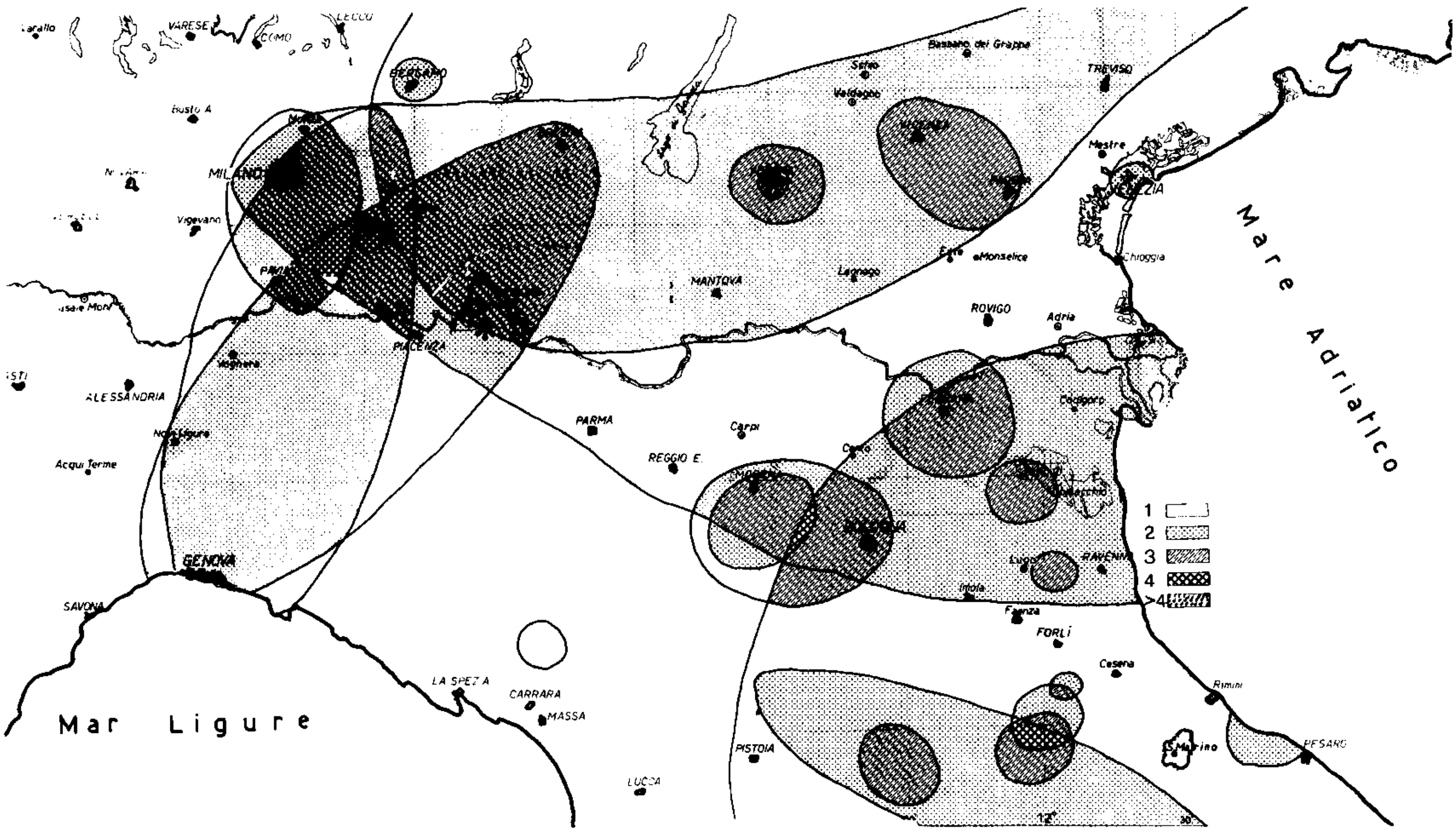

Fig. 9-3: Zones subject to earthquakes of intensity VIII.

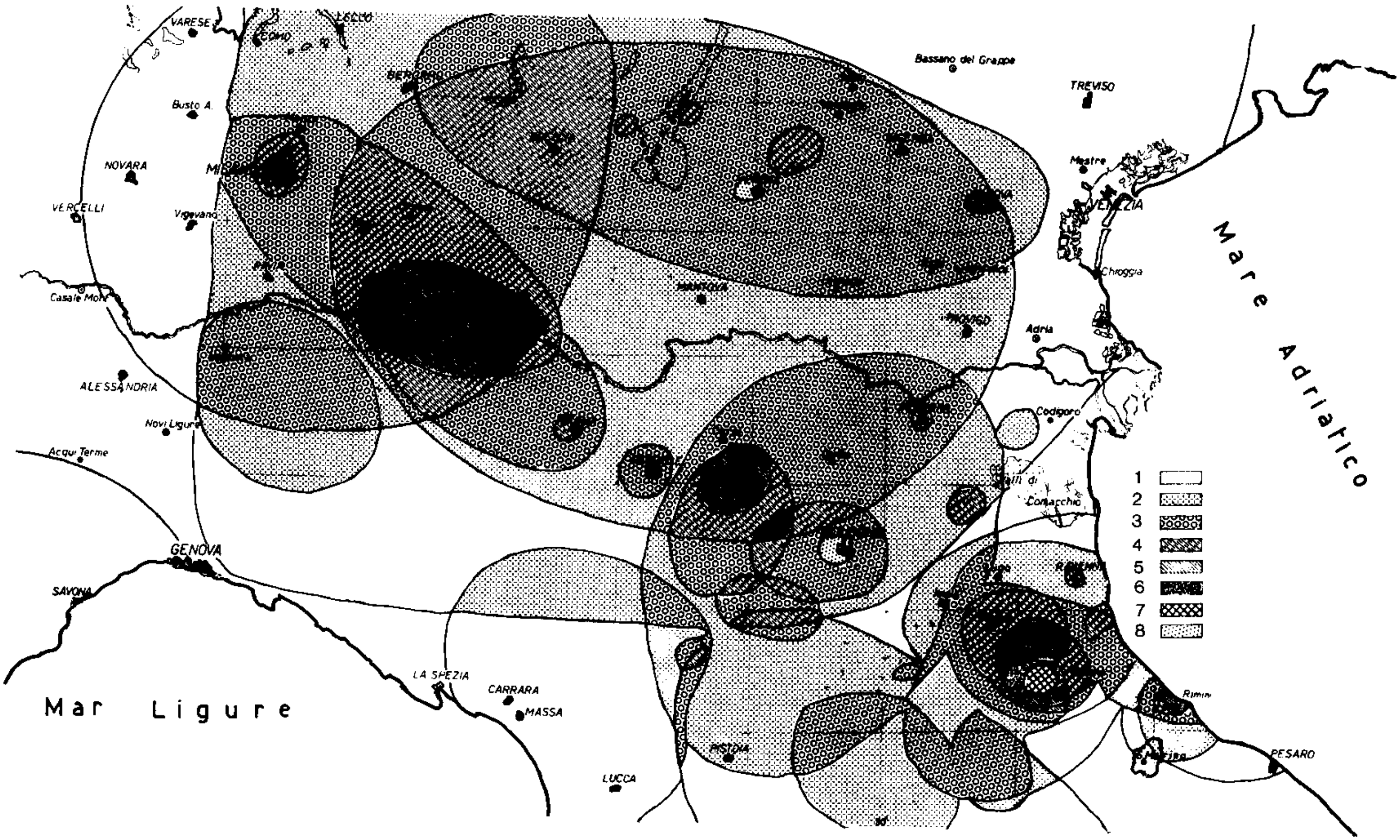

Fig. 9-4: Zones subject to earthquakes of intensity VII.

In the example quoted, the point chosen as the site has an Imax intensity of IX. The observed maximum intensity, on the other hand, is VIII. If the data for the last 50 years are ignored, the Imax intensity remains IX, while the observed maximum intensity is still VIII, although we have omitted from the data an earthquake of 1951, which, of all the recorded events, had its epicentre nearest to the site considered.

9.3 Microzoning in an area having varied subsoil conditions

At the time of the 1956 San Francisco earthquake, it was possible for the first time to make several recordings of earth acceleration at points close to each other in relation to the distance from the epicentre and having different subsoil conditions.

The recordings showed appreciable differences, both in maximum earth acceleration and in frequencies. In this connexion attention is drawn to Fig. 9-5, which shows a cross-section of the stratigraphic configuration at four of the recording points.

From the recordings of earth acceleration are determined the response spectrum (see annex I) and the maximum earth acceleration. This diagram and other similar ones which have since been prepared (especially at the time of the 1971 San Fernando earthquake) invite various observations, at least two of which should be included here:

a) In places where there are outcrops of base rock, the earthquake is characterized by greater accelerations (central diagram of Fig. 9-5) and a higher frequency of the dominant components

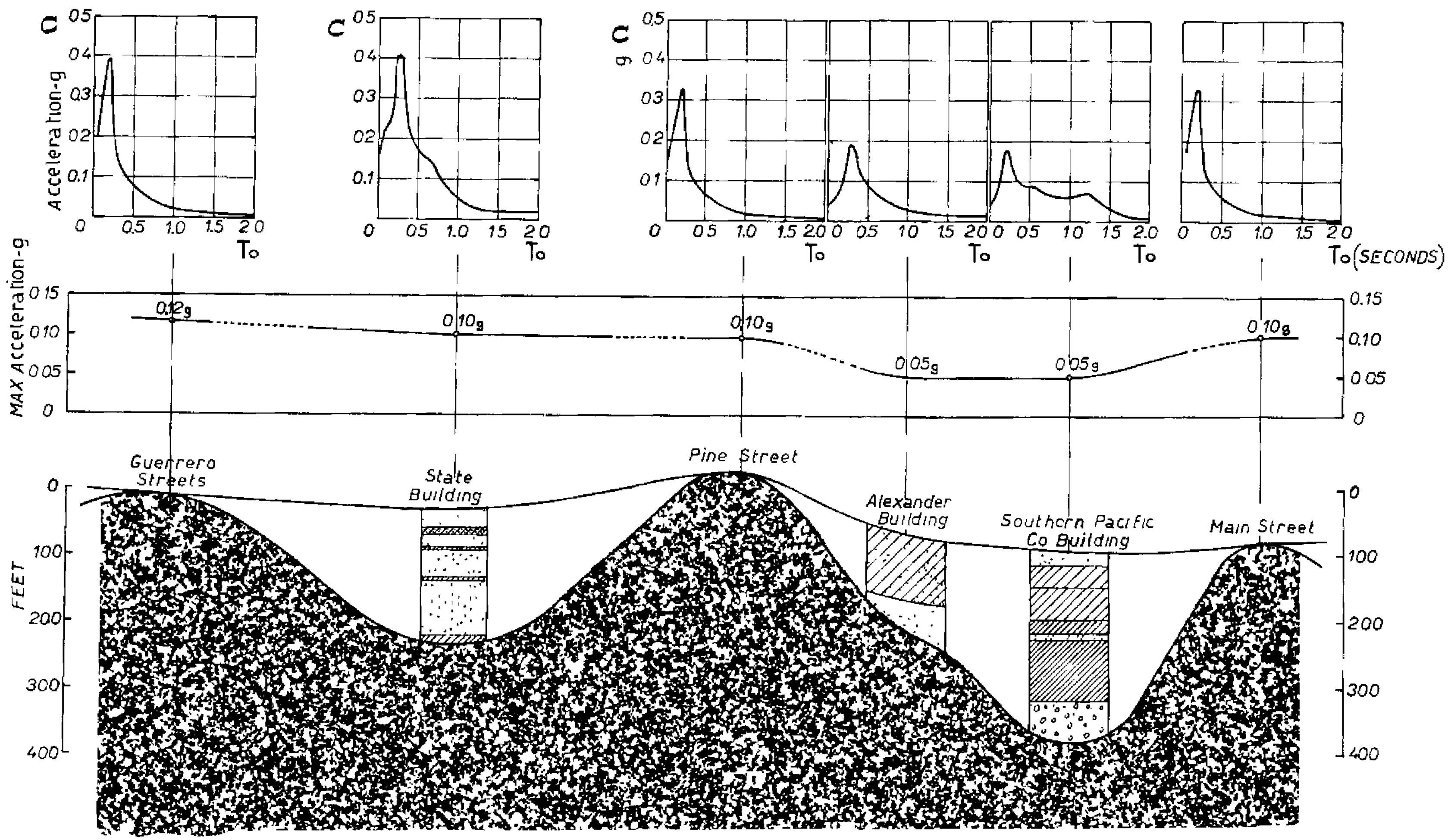

Fig. 9-5: Maximum acceleration in g and response spectrum, determined from recordings made at six different points during the San Francisco earthquake of 1906.

(peak of the graphs displaced toward the short T periods), which indicate a greater risk for most private dwellings and office buildings with few storeys. It should be noted that this type of result is not common to all sites;

b) In places where there are alluvial deposits some hundred metres deep, the earthquake can generate accelerations which are more damaging to very high, slender buildings such as skyscrapers with several dozen floors, (in graph C it is just above alluvial deposits that the ordinate values are highest for $T \geqslant 1$ sec).

The fact that the surface strata and, more particularly, the local geological characteristics, can have a great influence on the destructive effects of an earthquake had already become apparent from the study of damage sustained by identical buildings on different soils at the time of the San Francisco earthquake (1906) and the great Tokyo earthquake (1923).

Since then, countless observations relating to earthquakes in different parts of the world have made it possible to establish that there can be an extremely close correlation between the presence of loose surface strata and the local amplitude of seismic oscillations.

Moreover, it is very interesting to note that in some of the recent major destructive earthquakes (Nigata 1964, Anchorage 1964, Caracas 1967 and San Fernando 1971),which occurred at a time when earthquake-protection engineering already existed, the most extensive damage suffered by earthquake-resistant structures was caused by the abnormal dynamic behaviour of surface geological formations, in some cases covering a very small area. Above all, incredible differences were noted in the structural damage at sites very close to each other. For this reason, earthquake-protection engineers throughout the world are devoting a major part of their current research to quantitative definition of the effects of surface formations on seismic waves coming from the rock substratum.

It is not always possible to establish a relation between these observations and local recordings of earth acceleration. Instruments for recording strong accelerations have only existed since 1930, and the only one installed at Caracas during the 1967 earthquake did not work: the batteries were run down. Observation of the damage, however, was exemplary: no appreciable damage to buildings in practically the whole town; five buildings of 10 to 15 storeys destroyed, one half-destroyed, and many buildings damaged in a very small part of the town characterized by special geological conditions. It should also be noted that the five buildings which collapsed (killing 300 people) had been built in conformity with modern earthquake-protection standards and that no one questioned the quality of the work or the materials used.

This brings us to the effects of local geological conditions and the way in which, though still at the experimental stage and subject to caution, their study can provide useful information for urban planning and development in different parts of the world.

The general term "seismic microzoning" (MZ), which is often used to denote this kind of study may in reality cover different aspects of the problem, ranging from the purely seismological aspect of the definition of local intensities to the typically dynamic aspect of the analysis of wave propagation in strata of given characteristics.

In the Soviet Union for example, research on seismic microzoning has aimed mainly at defining, for a given zone (typical example : the territory of a town), "normative" values of "standard" intensity which would be recorded on hard ground (rock). The results are generally entered on 1/10,000 or 1/15,000 scale maps, which also show other significant seismic values, such as the predominant oscillation periods of the surface strata. The Soviet Union has precise rules for seismic microzoning studies.

In Japan, after an extensive programme of observations carried out by the Tokyo Institute of Seismological Research, the different types of foundation soil were classified on the basis of determination of the predominant periods of local microseismic noise.

In other countries having zones of high seismicity, like the USA and Mexico, the expression "seismic microzoning" is commonly applied to all research concerning the seismic response of the surface layers of the ground.

9.4 Techniques of seismic microzoning

The experience of the last 40 years shows that the most useful data for earthquake-protection engineering have been provided by recordings of the accelerations generated during violent earthquakes, i.e. accelerations of the order of 0.1 g or more. It follows that the most effective microzoning techniques should be based on the installation of local networks of accelerometers, which should be as dense as possible. This condition is rarely fulfilled, mainly because of the high cost of accelerographs. The most remarkable case so far is that of the Californian earthquake at San Fernando on 9 February 1971, for which no less than 241 accelerograms were obtained, 175 of them recorded at distances of less than 50 km from the epicentre (Los Angeles zone). We shall revert later to this particular case and some of its implications.

Even though there are not many countries in which populated centres are struck by earthquakes of magnitude 6 or 7, it will clearly take a number of years for a sufficiently dense instrumental network to be set up. At present there are certainly only two countries in which these conditions are partly satisfied: the USA and Japan, and a few other regions such as the Mexico zone where 12 accelerometer stations have been set up within a maximum radius of 80 km.

At first, the seismic microzoning experts of the different countries considered it easier to collect data by studying the medium or low intensity events which recur fairly frequently, even in countries with medium seismicity. In the limit, it would be desirable to analyse microseisms, which are earth vibrations of very low amplitude (of the order of 1μ) that can be observed everywhere at all times. Among the very numerous studies made of low intensity earthquakes, mention may be made of Gutenberg's work on the Pasadena area of California and the studies on various towns in the Soviet Union carried out by the seismic microzoning group of the Moscow Institute of Geophysics. The instruments used by Gutenberg were short-period Wood-Anderson seismographs. On the basis of the amplitudes recorded on different soils for the same event, Gutenberg proposed certain general principles of seismic microzoning. It is interesting to note that in the stations he used, strong acceleration recorders were subsequently installed, which provided an important series of recordings during the San Fernando earthquake.

A comparative analysis of Gutenberg's data on small shocks (M = 3 to 4 on the Richter scale) and the data collected during the San Fernando earthquake (M = 6.6) has recently been made by Hudson.

Hudson's main comment is that the position of the epicentre in relation to the zone considered and the effects of wave propagation on local oscillations may have been very different for Gutenberg's observations and those made during the violent San Fernando earthquake.

On this point Hudson concluded that "It seems clear that the distribution of ground oscillations predicted on the basis of simultaneous recordings at different sites for small earthquakes may not faithfully reflect the actual distribution which would be observed during a destructive earthquake..." ; he went on to say that : "It is only when a large volume of data is available, similar to those collected during the San Fernando earthquake, that it will be possible to begin to consider seriously making detailed maps of seismic risk".

Hudson's pessimistic views are not, however, shared by other experts. There are now portable strong-acceleration recorders with which, once foreshocks have been felt in a particular place, a large number of recordings of the main shock and aftershocks can be obtained. This technique was used in 1972 at Ancona, in Italy, where 19 accelerograms were recorded, some of which showed maximum accelerations of the order of 0.5 g at three separate points in the town.

Another possibility is the study of microseisms which involves detailed treatment of a number of rather complicated theoretical and practical questions. For more exhaustive treatment of the subject, the reader is referred to the recognized bibliographies. In the light of the extensive research carried out in Japan by Kanai and his co-workers, the most important argument in favour of this method seems to be that the predominant frequencies and certain spectrum characteristics of microseisms recorded on alluvial surface strata often coincide with the recordings of earthquakes made at the same place. In a large number of cases it has been possible to make comparisons with destructive earthquakes.

The most valuable information that one attempts to obtain from microseisms relates to the oscillation period of the surface layers, which is usually easy to correlate with the values that can be theoretically calculated by analysis of elastic wave propagation. It is clear that the theory of elastic behaviour of the soil in conditions of microseismic vibration is highly plausible, but it may cease to be valid for earthquakes of a certain intensity. In addition, the looser the layer of soil concerned and the more it differs seismically from the hard underlying formations, the more marked will be the difference in behaviour. The most highly qualified experts now consider that the techniques of microseismic observation provide a useful tool for seismic microzoning in the case of relatively compact surface layers not more than a few tens of metres thick. One example is the seismic microzoning work carried out for the town of Skopje, Yugoslavia, on the basis of a study of microseisms, which showed good correlation between the predominant frequencies, the thickness of the alluvial strata and the distribution of damage during the destructive earthquake of 1963. This technique is not recommended, however, in the case of very loose surface layers which lack cohesion and are of great thickness.

This section will conclude with an observation which is very important from the practical point of view. Whatever the instrumental technique used for seismic microzoning (strong-motion accelerographs, short-period seismometers for small shocks, observation of microseisms), it is essential to carry out: 1) a preliminary geophysical examination of the area to ensure realistic interpretation of results in the light of the local geology ; 2) static and dynamic laboratory analyses of soil samples, to obtain plausible values which can be used in discrete mathematical models to simulate real behaviour in situ under seismic excitation of a given type.

Laboratory tests are mainly useful in studying the dynamic behaviour of saturated surface soils in which instantaneous collapse phenomena similar to liquefaction may occur.

The main object of on-site prospecting should be to determine the propagation speed of the S waves and the thickness of the geological surface strata. In addition to conventional techniques (geophone networks on the surface), use should also be made of techniques of measurement by drilling, which consist in sinking a bore-hole to the required depth and placing a special seismometer in it which records, at different depths, the arrival of waves from an artificial source close to the top of the bore-hole.

Lastly, if very detailed data are available on the local stratigraphy and mechanical properties of the soil, theoretical numerical models of seismic microzoning can also be developed. A large number of researchers at the University of Berkeley (California) have carried out work of this kind and developed different methods of calculation (SHAKE, QUAD 4, LUSH, FLUSH).

Fig. 9-6 shows the variation in amplitude of the response spectrum, measured at different points of the surface of an alluvial layer. The results arrived at by calculation are similar to those obtained from direct empirical recordings, as in the case of the preceding figure.

It should be noted that theoretical numerical calculation is no longer confined to small oscillations; all the methods of calculation mentioned admit the non-linear effects which are characteristic of strong oscillations. It therefore appears that this method should make it possible to go beyond the limits of validity mentioned in connexion with the study of microseisms for seismic microzoning.

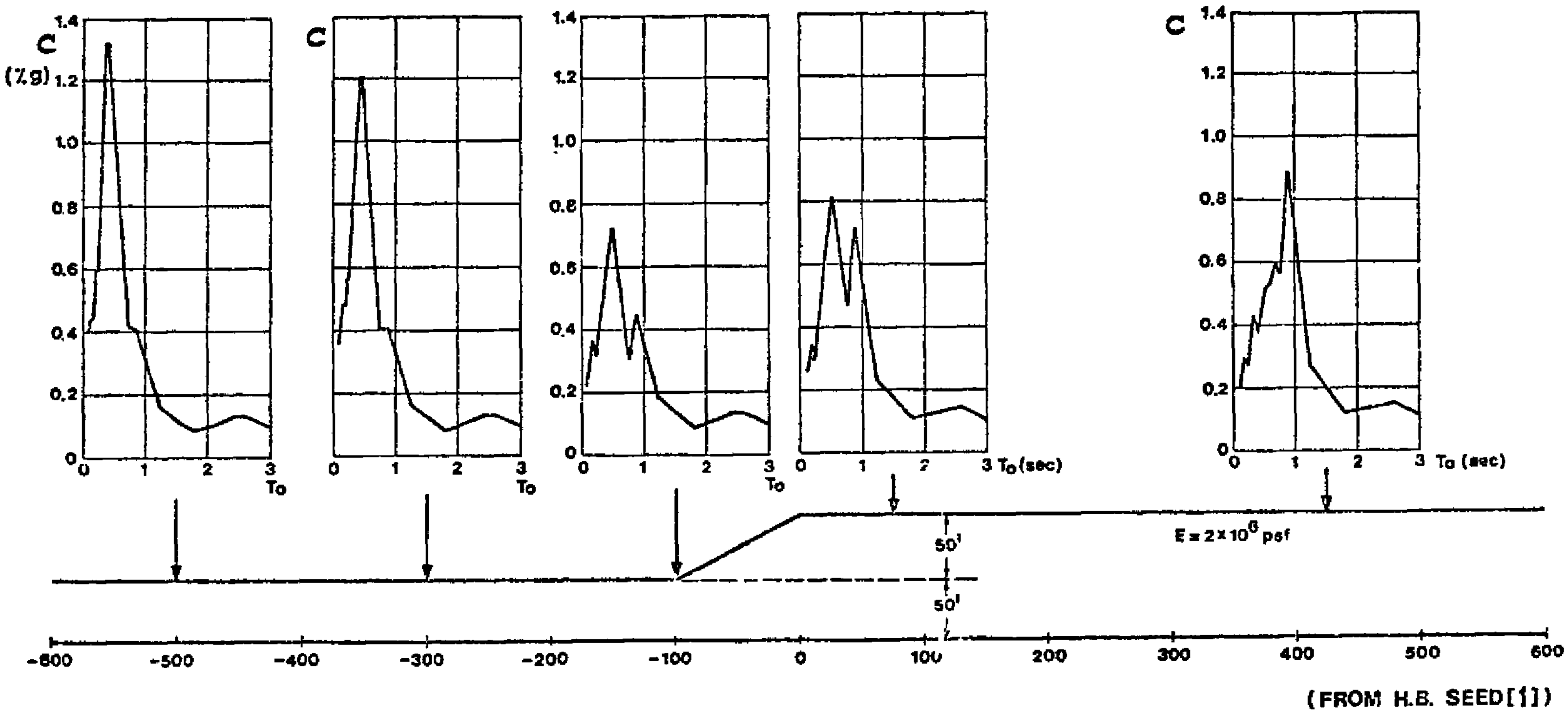

Fig. 9-6: Variations in the response spectrum as a function of distance (obtained by numerical calculation). It is assumed that there is a stratum of rock beneath the deposit.

UNESCO has been studying a few of the above-mentioned techniques for some time, with a view to preparing instruction manuals. A manual of this kind was submitted by the delegation of the USSR at the Intergovernmental Meeting on Seismology and Earthquake Engineering held in Paris in 1964. It is entitled "Instruction Manual for Seismic Microzoning" (UNESCO/SM/Seism/Rep/R, Paris 1964). Several studies summarizing the techniques were submitted at the recent Intergovernmental Conference on the Assessment and Mitigation of Earthquake Risk, convened in Paris by UNESCO in February 1976.