Seismicity and Earthquake Ground Motion

(SESSION III)

NOTE: Only questions answered in written form by the author are included in the discussion.

SESSION III

SESSION III (Cont'd)

ABSTRACTS

Third World Conference on Earthquake Engineering

Reporters' Summary

Theme III. Seismicity and Earthquake Ground Motion

by

Donald E. Hudson

California Institute of Technology

The eighteen papers from all parts of the world which have been submitted under Theme III cover in a comprehensive way most of the aspects of the subject of Seismicity and Earthquake Ground Motion which are of current importance. The primary object of the present summary is to show the relationships between the various contributions and to the whole field of Earthquake Engineering. A secondary objective is to call attention to certain aspects of the subject which have not been treated in the submitted papers, and which may not at the moment be receiving adequate study and consideration. This summary is not intended in any sense to be a critical review of the papers: discussion and criticism of specific points will naturally develop during the presentations of the papers that are to follow.

As in any lively field of strong current technical interest, there are a number of controversial subjects to be touched upon, and it is to be hoped that many of these matters can be resolved or at least clarified in the course of the discussions.

The following outline shows the major topics to be included in the present session, along with the names of the authors who have contributed to the various items. A number of subjects have been included for which no contributions have been received for the present conference. As indicated above, this has been done to call attention to some aspects of the subject which are not being pursued as actively at present as might be desirable.

Theme III. Seismicity and Earthquake Ground Motion

A. Instrumentation and Measurement.

1. Strong Ground Motion

    a. Accelerographs (Duflou-Skinner, Halverson)
    b. Response Recorders (Jai Krishna-Chandrasekaran)
    c. Strong-Motion Seismometers

2. High Sensitivity Seismographs

a. Teleseismic equipment, world wide networks
b. Portable stations for local studies
c. Microtremor devices

B. Basic Description Methods

1. Intensity Scales (Eiby)
2. Magnitude Scales
3. Energy Relationships

C. Ground Motion Data

1. Natural Earthquakes

a. Accelerograph records--large earthquakes
b. High-precision local networks (Bune)
c. Microtremors (Yershov-Lyamzina-Shteinberg)
d. Maximum ground motion studies (Dick, Housner, Lacer, Puchkov)

2. Artificial Excitations

a. Explosions and blasts (Jenschke-Clough-Penzien)
b. Impacts (Yershov-Lyamzina-Shteinberg)
c. Vibration Generators

D. Analysis Techniques

1. Seismicity

a. Epicenter maps (Bune)
b. Recurrence plots (Bune)
c. Extreme value statistics (Dick, Milne-Davenport)
d. Strain release studies (Brooks, Milne-Davenport)

2. Ground Motion

a. Fourier Spectrum techniques (Yershov-Lyamzina-Shteinberg)
b. Power spectral density (Ravara)
c. Response spectrum techniques (Jenschke-Clough-Penzien)

E. Geologic and Tectonic Relationships

1. Surface layer effects (Lacer, Yershov-Lyamzina-Shteinberg)
2. Earthquakes and Faults (Bune)
3. Earthquakes and Geotectonics (Medvedev, Srivastava-Mithal)

F. Seismicity of Particular Regions (Brooks, Bune, Hsu Ming-Tung, Medvedev, Milne-Davenport)

G. Seismic Zoning and Microzoning (Bune, Medvedev)

H. Prediction (Carder)

It will be evident from the above outline that the particular subjects included under Seismicity and Earthquake Ground Motion are just those for which it is most difficult to draw the line between seismology and earthquake engineering. It is also the aspect of the subject in which the closest cooperation between those two groups must be insured. It must be expected that from time to time certain of these subjects will be turned over to the engineers by the seismologists, either because of a decline in basic scientific interest in the topic, or because the subject may have acquired immediate practical importance in construction practice. It is important that earthquake engineers recognize this process, and remain always in a position to advance such subjects on their own initiative. It is also necessary to avoid a certain difficulty which often assails such closely related fields. Certain topics may get lost between the two groups, with each party supposing that the other is pursuing the investigations. Earthquake Engineering has suffered from this on a number of occasions, and it is an important object of the present meeting to eliminate such misunderstandings from the subject.

The various topics will now be taken up in the order in which they appear on the outline, and for each a brief summary of the various contributed papers will be given.

Instrumentation and Measurement. One of the most important sources of information for Earthquake Engineering are records of true ground acceleration during large earthquakes. Such measurements present many experimental difficulties and all existing strong motion accelerographs suffer from various defects. The paper by Duflou and Skinner describes two new accelerographs which are in a late stage of development and which have a number of interesting new features. The first device is a strong-motion accelerograph which records three components of true ground acceleration on a 35 mm. film. The natural period of the transducer elements is about 30 cps, rather higher than current accelerographs, and the optical magnification is such that lg acceleration gives a displacement of 12.5 mm. on the film. A film speed of 1.5 cm/sec is used, with timing based on a constant motor speed. An especially interesting feature is the vertical starter of the velocity type which operates on an induced E.M.F. and hence requires no mechanical contact and is not subject to D.C. drift difficulties. It is stated that many simplifying features have resulted in an accelerograph which should be appreciably less expensive than present devices, and this would of course be a most important contribution to a wider distribution of such instruments.

A second instrument described by Duflou and Skinner is a peak reading accelerograph, consisting of a 0.05 second inverted pendulum and a scriber which gives a mark of 0.090 in. per lg on a smoked glass. The glass plate record is photographically magnified by 100X. The combination of a relatively short period and 60% oil damping makes this device a true ground accelerometer for most important strong ground motions. It is proposed that these low-cost peak-reading accelerographs be used to supplement the more complex time-recording devices, and it is indicated that some 100 of these instruments are to be distributed throughout New Zealand.

The paper by Halverson gives a convenient summary of currently existing strong-motion accelerographs, with a description of basic principles, pictures of representative devices, and a tabulated outline of significant characteristics. It is only in the past few years that such instruments have become commercially available in a form suitable for widespread application on a routine basis. There is now an essential agreement on the major characteristics which such instruments should have so that the main problems remaining in the establishment of strong-motion accelerograph networks are mostly financial, and to a lesser extent those of training of personnel for the installation and servicing of the instruments.

It is probably fair to say that all existing strong-motion accelerographs have been developed under fairly strict financial limitations, so that the potentialities of the most modern techniques of instrumentation have not been fully exploited. It is recognized by everyone, for example, that it would be very advantageous to have the record in a form of a conveniently generated electric signal, as on a tape. Even more to be desired would be a transducer which produced a direct digital record, which could then be introduced into modern computing facilities for analysis. This and other developments leading to increased field reliability and convenience of installation must await a greatly increased awareness of both structural engineers and seismologists in the basic importance of the missing data. Recent technical publications from the USSR have indicated very active development programs in this area, with equipment based on magnetic tape-memory systems, xerographic recording, and photo-luminescent storage systems.

Under the name "response recorders" are included instruments which are not intended to measure directly some parameter of true ground motion, but rather are expected to indicate the response of a typical structure to such ground motion. Such devices can properly be called "response spectrum" recorders, since they produce directly at least one point on a response spectrum curve. In the U. S. A., simple low-cost devices of this kind are usually called "seismoscopes". The paper by Jai Krishna and Chandrasekaran describes the use of a series of simple seismoscopes having different natural periods and damping to cover a wide range of the response spectrum. It is pointed out that regions of the world in which there are no recording accelerographs to aid in the interpretation of seismoscope records require more information than is likely to be obtained by one seismoscope, and that multiple seismoscopes of various characteristics may be a practical solution of the problem. For India, a system involving six instruments having natural periods of 0.40, 0.75, and 1.25 sec, and damping of 5 and 10% is being installed. This multiple instrument approach may be compared with the principle of designing one instrument having multiple elements, as exemplified by the USSR AIS-2M multi-pendular seismometer.

Under the subject of strong ground motion measurement in the outline, is also included an item "strong-motion seismometers" by which is meant the low magnification instrument occasionally found as a part of the equipment of teleseismic seismographic stations. It is important that earthquake engineers understand that what most seismologists mean by a strong-motion seismometer is an instrument significantly different from the strong motion accelerograph which is so important to the engineer. This point has been touched upon in the paper by Halverson. A strong-motion seismometer usually has a natural period of around 1 second and a magnification of perhaps 4x to 10x, and its function is to give records of very strong earthquakes that throw the regular instruments off scale. The recording speed and period are such that ground accelerations cannot be obtained to the accuracy required by the engineer, but nevertheless such recordings would often be of great interest to the engineer. After the 1964 Alaska earthquake, for example, all of the sensitive seismographs within several thousand miles were off-scale for a considerable time, with a resultant loss of much information that would be of the greatest importance in studying the earthquake. The number of strong-motion seismometers in seismographic stations should be greatly increased, and this should be the subject of joint discussions between seismologists and engineers.

It is not surprising that there are no special contributions related to high-sensitivity seismographs at the present conference, since this is a subject primarily for seismologists. There is an increasing interest, however, in the use of such equipment for special studies of direct interest to engineers, such as for seismic regionalization investigations, and in the future it will be important for engineers to be aware of possibilities of modern instrumentation of this type.

It would be appropriate at this point to mention the great progress that has recently been made towards a relatively complete coverage of the whole earth from the standpoint of teleseismic epicenter location. After a discussion of this matter at the recent UNESCO Intergovernmental Meeting on Seismology and Earthquake Engineering, it was concluded that considering the existing networks of modern stations with accurate instrumentation, only an additional dozen or so stations in the right spots would be needed to essentially complete an adequate world wide network. The time is thus rapidly approaching when the data on the occurrence and epicentral location of earthquakes will be for practical purposes complete for all earthquakes of a magnitude greater than 4. This will of course vastly facilitate future studies of seismicity and should result in a considerably improved detailed picture of the distribution of seismicity over the earth.

A type of high sensitivity equipment of a direct interest to the engineer is that suitable for portable temporary stations for precision epicentral location studies in connection with local seismicity studies, and for use in studies of aftershocks of large earthquakes. Modern instrumentation techniques should make it possible to develop equipment of this type considerably more convenient in use than existing devices. It will ultimately be advantageous to earthquake engineers to encourage increased work in this direction. Similarly, engineering applications of microtremor studies are becoming more widespread, and it is to be hoped that improved instrumentation of this type will be forthcoming.

In summarizing the instrumentation picture, it may be concluded that at present the most pressing matter for the earthquake engineer is still the problem of providing more recording accelerographs. For none of the recent earthquakes causing major damage--Chile, Agadir, Iran, Skopje, Alaska--has there been even one record of strong ground motion. Although the number of recording accelerographs in the world has increased from some 75 at the time of the 1st World Conference in 1956 to about 300 at the present time, it is evident that a vastly increased network will be needed if the basic data is to be significantly enlarged. This problem was discussed in detail at the recent UNESCO Intergovernmental Meeting on Seismology and Earthquake Engineering, and the outlines for a plan of international cooperation were formulated. The implementation of this plan and the necessary extension of the strong-motion accelerograph networks in the various seismic regions will call for extensive activity on the part of earthquake engineers in all countries.

Basic Description Methods. An evaluation of the current status of earthquake intensity scales is given by Eiby, who strongly advocates the retention and development of local intensity scales for basic studies of interest to both seismologists and earthquake engineers. He suggests, for example, that a really complete coverage of the seismic regions of the world by suitable strong-motion instrumentation is permanently unlikely, and hence a subjective assessment of intensity may remain the only source of data for many important earthquakes. He also cautions against an excessive zeal in the promotion of an International Intensity Scale, on the grounds that this might tend to deprive some areas of important local special features which might increase the accuracy of the local intensity evaluations without compensating advantages.

In this connection, it is worth drawing attention to the studies on a standard intensity scale which were reported at the 13th general assembly of the I. U. G. G. (1963) in Berkeley by Medvedev, Karnik, and Sponheuer, and which were discussed at the recent UNESCO Intergovernmental Meeting on Seismology and Earthquake Engineering in Paris. The main object of these new proposals, which involve small alterations of the "standard" Modified Mercalli Intensity Scale, is to reduce ambiguities in the definitions of the extent of damage and of the nature of typical structures, and to draw more accurate distinctions between the effects of earthquakes on people, structures, and geology. It was recognized at the UNESCO meeting that engineering representatives had not participated in the deliberations on this new Intensity scale and it was recommended that several earthquake engineers should be added to the IUGG committee to insure a proper cooperative effort. Since this subject has not been specifically brought up in any of the submitted papers, it would be well here to bring to the attention of all earthquake engineers the importance of these studies, and to recommend that engineers should play an active role in this matter, and not leave the whole initiative to the seismologists.

A closely related subject is that of magnitude scales, which has also been the object of discussions at the IUGG and the UNESCO meetings.

Here again there are no special contributions to the present conference on this subject, but it would appear to be of the first importance that earthquake engineers should understand thoroughly the current thinking on these basic measurements. The engineers' ideas on seismicity must depend in a very direct way on the information obtained from seismologists in the form of earthquake magnitudes and the engineer must always know how to accurately evaluate this information.

In this same connection, some comments should be made on current developments of energy scales. Everyone agrees that the total amount of energy released during an earthquake as seismic waves would be the single most important measure of the size of an earthquake, but there is a considerable difference of opinion as to the accuracy with which this can be done, or the level of accuracy that would be acceptable for practical purposes. At present, it is most usual to derive the energy in a secondary way from the magnitude using empirical relationships. Richter has recently clearly explained again why he has preferred a magnitude scale to an energy scale, and has reminded seismologists of the difficulties of arriving at a meaningful measurement of energy in the following quotation: "It will be observed that definition [of magnitude] here follows the general practice in modern physics, of definition in terms of observed quantities directly. Some voices are occasionally heard in criticism; it is said that instead the magnitude should have been defined at once in terms of radiated energy. It ought to be obvious that there is sufficient difficulty in arriving at a satisfactory evaluation of the magnitude defined in observable terms, without introducing the complicated and sometimes actively disputed relation between magnitude and energy."* In this same discussion, however, Richter has recognized that the existence of modern computing techniques and the vastly increased amounts of data which are now becoming available should make it possible to much improve such energy studies.

These more intensive studies of energy considerations have in fact been underway for some time in the USSR and there is an increasing tendency for USSR seismologists to report seismicity data in terms of "energy classes". For example, in a paper submitted to the present conference by Bune, earthquake sizes are expressed in terms of the energy class K, where $K = \log E$, E being the energy in Joules. This energy class can be related to magnitude M through the usual energy-magnitude expressions, giving a relationship of the form $K = aM + b$, where a and b are constants. It may be hoped that in the near future these increased studies of energy characteristics of earthquakes will make it feasible to adopt a universally agreed upon energy scale for the quantitative assessment of seismicity.

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*Richter, C. F., "Historical Background of the Magnitude Scale," Proceedings of the Vesiac Conference on Seismic Event Magnitude Determination, Acoustics & Seismics Laboratory, Institute of Science & Technology, The University of Michigan, 1964.

Ground Motion Data. Consideration will now be given to the information on actual earthquake ground motions which is to be presented to the conference.

It should first be pointed out that no new accelerograms of strong earthquakes are presented by any of the contributions to Theme III. The reasons for this unfortunate state of affairs has already been discussed, but it would perhaps be well to again emphasize the difficulties that the earthquake engineer finds himself in because of the absence of this basic data. Since the Second World Conference in 1960 several interesting accelerograms of small but significant earthquakes have been obtained in Japan and in Mexico and have been described in the technical literature. It can be hoped that by the Fourth World Conference there will be a substantial increase in the number of good accelerograms of strong earthquakes for analysis.

Concerning the use of small natural earthquakes for studies of local seismicity, a paper from Bune is to be presented which describes in detail very complete investigations of a particular area. This study involved some 10 - 18 seismographic stations located 30-60 km apart. In the 5 years from 1955-1959 some 2000 epicenters were located to an accuracy of ±5 km. This relatively large amount of precision data permitted a much more comprehensive study of the relation between epicenter locations and geologic faults. The basic parameters describing the relationship between number of earthquakes and energy class were ascertained for the area, and the stability of these parameters with time was studied. The relationships between occurrence of earthquakes and the local and general geotectonic status of the region were explored. Methods of employing such precision data for the formulation of seismic zoning maps were also investigated. The fruitful results of these investigations offer the hope that other regions of the world can be studied with an equal thoroughness.

Another type of natural ground disturbance which can perhaps throw light on seismic zoning problems are those small vibrations continually occurring in the earth called microtremors. A paper submitted by Yershov, Lyamzina, and Shteinberg shows how microtremor measurements can be interpreted to yield information on surface layer conditions at a particular site. This investigation involves a comparison of ground amplitudes from small natural earthquakes and microtremor amplitudes with the surficial structure derived from analytical studies based on experimentally determined velocities of propagation. These three types of measurement were made at five sites having different soil and foundation conditions. The data indicates a reasonably good agreement between amplitude ratios for microtremors and for small natural earthquakes at the various sites.

A very important question in earthquake ground motion is that of ascertaining the maximum possible ground motion that is likely to result from great earthquakes. It has long been realized that the maximum strength of the materials of the earth's crust should impose some limit on the maximum strain energy that can accumulate, and hence on the size of the maximum possible earthquake. Various aspects of this problem have been treated by four contributors, making this one of the most popular subjects under Theme III.

Puchkov has presented an analysis based on a simplified physical model, an assumed ultimate dynamic strength of rocks, and an assumed duration of earthquake shocks, which indicates that the maximum earthquake should correspond roughly on rock to a modified Mercalli intensity of VII. Considering the increased intensities to be expected on soft soils, this conclusion is thought to be consistent with experience in past earthquakes as embodied in the standard intensity scales. It thus appears that there are no major ambiguities involved in explaining past earthquake damage by simple physical considerations.

The problem is approached from another point of view by Housner, who calculates the peak acceleration to be expected near a fault plane assuming the worst case that all of the seismic energy goes into one single pulse. Computations based on known physical properties of materials and on past knowledge of the extent of fault motions indicate an upper bound of the order of 50% g, which is believed to be consistent with past experience. A study of existing data indicates additional upper bounds of approximately 45 seconds for the duration of strong ground motion, and a magnitude 8.5 as an upper magnitude bound for design considerations.

An estimate of the maximum ground motion to be expected at a particular site in a given time period is given by Lacer. He compares conditions to be expected if epicenters are randomly distributed over an area, with those in which the epicenters are distributed in some random way along certain well-defined fault zones. In arriving at the maximum possible ground velocities, resonant effects of surface layers are considered. It should perhaps be mentioned that the upper bounds of ground motion derived by Lacer seem extraordinarily high compared with other analyses and with past measurements, and it thus appears that there still remains a considerable difference of opinion on this important subject.

In connection with a study of New Zealand earthquake statistics, Dick has applied extreme value statistical theory to world earthquakes. He shows that an extrapolation of past data to a thousand year period indicates a maximum possible shock of the order of magnitude 9-1/2, which he regards as being in general agreement with seismologists' views on the biggest possible earthquakes.

The possibilities of artificial excitation of ground motion have perhaps not been fully exploited by earthquake engineers for structural response experiments. Tests have shown that the ground motions produced by large explosive charges such as quarry blasts are very similar to the initial portions of large earthquake ground motions. Such blasts are often used for commercial purposes, and may sometimes be available for test purposes as well. The paper of Jenschke, Clough and Penzien includes a considerable amount of data on ground accelerations and response spectra of a series of underground nuclear explosions along with similar data for earthquakes so that comparative studies can be made.

The only other mention of artificial ground excitations for purposes related to earthquake engineering occurs in the paper by Yershov, Lyamzina, and Shteinberg. In connection with studies of the effects of surface layers on earthquake ground motion, they have experimentally determined the velocities of propagation of waves in the surface layers by impact methods. Such impact methods as well as vibration generator techniques should be of great assistance in direct experimental determinations of in situ ground and rock conditions.

Analysis Techniques. A group of papers dealing with analysis techniques will now be considered, first mentioning several ways in which basic seismicity data have been treated.

The way in which a considerable amount of information can be included in an epicenter map, and such maps used to elucidate the relationships between earthquakes and faults, is well illustrated in the paper by Bune. He has also given a comprehensive example of the use of recurrence plots of number-of-earthquakes vs. energy, including a study of the stability of the plot parameters with time.

The mathematical techniques of extreme value statistics have been applied by several investigators to the earthquake problem with interesting results. The paper of Dick uses these methods to examine the seismicity of New Zealand, and to compare that area with the world and with Southern California experience. It is shown that this statistical approach gives results which fit the past record of experience very well, and which leads to meaningful statements about the occurrence of future large earthquakes. It is interesting to note that the seismicity of New Zealand seems in many respects to be very similar to that of California, perhaps suggesting causative mechanisms of at least a Pacific Ocean scale. Similar conclusions as to the validity of extreme value statistics are arrived at by Milne and Davenport, who have applied these techniques to a small region of Western Canada. They suggest that the basic parameters used in extreme value statistics might well be adapted as a fundamental measure of seismicity, since these parameters point directly to the type of information on maximum expected earthquakes which is of prime interest to engineers.

Past investigations have shown the value of a consideration of the rate of strain accumulation and release in the earth's crust by earthquakes. In connection with a study of the seismicity of New Guinea and Papua, Brooks makes use of strain release curves to establish trends over relatively long periods of time. It is to be hoped that as more and more information of this kind is accumulated the full significance of such trends will become clearer and will facilitate extrapolations to future strain release conditions. Similar studies have been made for a small area of Western Canada by Milne and Davenport, who present contour maps of strain release per element of area for a given time interval, and indicate that a tendency exists for these contours to follow local geological features.

Turning next to the problem of the analysis of ground motion records, several methods are found to be employed by various contributors. The use of Fourier Spectrum techniques for frequency analysis is well illustrated in the paper by Yershov, Lyamzina, and Shteinberg. The applications are to records of earthquakes on different ground conditions, and to comparative records of small natural earthquakes and microtremors. These frequency spectra exhibit the results in a very illuminating form which much facilitates a comparison of theory and experiment.

Another type of frequency analysis is employed by Ravara, who plots the power spectral density curves for a number of strong motion earthquake ground motions. The concept of the power spectral density of the ground acceleration is closely related to the treatment of earthquake ground motions as series of random events, thus bringing the subject under the scope of the theory of stochastic processes. Ravara shows a good quantitative agreement between response calculations based on these power spectral densities and those derived from response spectrum techniques.

Response spectrum techniques themselves have been examined and extended in the paper by Jenschke, Clough, and Penzien. They show the exact relationships between five different response spectra which have been or might be used, and they conclude that the absolute acceleration response spectrum is the most appropriate one for classifying ground motion events. It is shown that this absolute acceleration response spectrum has characteristic shapes for typical earthquakes and blasts, and the frequency at which the acceleration spectrum peaks is suggested as a significant parameter for describing these shapes. As an application of this method of analysis, it is shown that there is a useful correlation between this frequency of acceleration peak and epicentral distance for strong earthquakes.

Geologic and Tectonic Relationships. It has long been recognized that local geological and soil effects can have a great influence on earthquake ground motion, but the enormous complexity of most local geological conditions has made it difficult to make any theoretical approach to the problem. It has been possible, however, to throw some light on these questions by considering highly simplified models, one of which consists of one or several horizontal surface layers. The paper by Yershov, Lyamzina and Shteinberg compares the amplitude-frequency curves measured for small natural earthquakes and microtremors with computations based on a surface layer model. The properties of the surface layers were experimentally determined by impact experiments, and the calculated responses involved such parameters as depth of layer, density and velocity of wave propagation product, angle of wave arrival, and number of cycles of incident pulse. It is shown that the simplified model retains many of the important features of the true physical situation as measured at five sites having different soil conditions.

The results of an extensive local experimental investigation of the relationships between earthquakes and faults is presented by Bune, who by means of a relatively dense network of sensitive seismographs was able to obtain large numbers of high-precision epicenter locations in a region of known fault characteristics. He shows by means of epicenter and fault maps and a statistical analysis that the regions in which faults branch off and intersect correspond to a high density of epicenters.

More general considerations concerning the relationships between earthquakes and tectonic processes are summarized by Medvedev, who points out the importance of geotectonic investigations in connection with seismic zoning studies. An example of such studies for a particular region is given by Srivastava and Mithal, who have examined in detail the tectonic processes at work in the Indo-Gangetic plains, and have correlated such processes with seismicity patterns. They show that a general consideration of the large scale tectonic development of the whole subcontinent reveals a clear pattern of major tectonic regions which correlates well with the known seismic features of the area.

Seismicity of Particular Regions. In addition to the more general studies mentioned above, a number of contributions have made important additions to the knowledge of the seismicity of specific areas.

Among the papers already referred to, Brooks summarizes the seismicity of the Territory of Papua and New Guinea based on records of earthquake of magnitude 6 or greater from 1906-1962. Intensity zone maps showing the "expected highest intensity" for time intervals of 25 years, 50 years, and 100 years are given. Milne and Davenport give the distribution of seismicity parameters for an area of Western Canada, according to extreme value statistics as mentioned above. Bune presents a detailed seismicity map of a particular local area in which dams are to be constructed, and Medvedev gives a general seismic zoning map for USSR territory embodying the most recent investigations.

The geographical distribution of Taiwan earthquakes of magnitude greater than 4.8 for the period 1933-1958 is given by Hsu Ming-Tung, who presents also epicenter maps for various magnitude classifications throughout the Island. A description of a six-point intensity scale customarily adopted for Taiwan is also included.

Seismic Zoning and Microzoning. The subject of seismic zoning, which has so many important implications for earthquake engineers, has been summarized in a general way by Medvedev, who outlines the basic methods now in use. He describes the way in which data on past earthquakes, geotectonic studies, and investigations of local conditions by recording of small earthquakes may be combined to give the best picture consistent with a current state of knowledge. A new seismic zoning map of USSR territory prepared during 1961-1964 is presented which embodies many recent investigations including a consideration of various soil conditions.

The problems of micro-regionalization are well illustrated by the intensive study of a particular area reported by Bune, previously referred to. It is pointed out that the results of short-term seismic observations must be considered in relation to the seismic history of a region over a long period of time, and that the geotectonic features under study must include a sufficiently large area to be really typical of the basic processes involved.

Earthquake Prediction. The very interesting problem of earthquake prediction is brought to the attention of the conference by a paper by Carder. He describes several research techniques which would be of value in this long-range problem such as crustal strain measurements involving precision geodetic measurements, tiltimeters and strain meters, geomagnetic investigations, and seismo-acoustic studies of ultra high frequency earth motions. Research programs along these lines are proposed for certain specific regions of known tectonic activity.

The subject of earthquake prediction is perhaps an appropriate one to close the summary of Theme III papers on seismicity and earthquake ground motion. Even five years ago, the subject of prediction was one that could hardly be considered as quite respectable by seismologists. The enormous increase in data collection and processing capability that has recently occurred, however, has placed the matter on a new footing, and today there is a serious interest in a thorough investigation of the possibilities of prediction.

A few recent developments connected with the prediction problem may be briefly mentioned. In January 1962 a very interesting progress report "Prediction of Earthquakes" was issued by the Earthquake Prediction Research Group of the Earthquake Research Institute, University of Tokyo. This report discussed in a comprehensive way the past scientific work related to the prediction problem, and suggested specific programs of research to carry these studies forward. This same subject was then taken up by a joint U. S. -Japan special conference, which met in Tokyo in March 1964. This conference reached the general conclusion that while specific earthquake predictions are not now possible, a number of promising lines of investigation offer hope that at some time in the future fairly detailed predictions can be accomplished. In April 1964 the UNESCO Intergovernmental Meeting on Seismology and Earthquake Engineering in Paris took note of the prediction problem and strongly recommended that special studies related to this problem be carried out with full international cooperation. In September 1964, as a consequence of the Alaska Earthquake, an Earthquake Prediction Panel was set up in Washington by the Office of Science and Technology under the initiative of the President's Science Advisor. It may thus be said that official recognition of the validity of work in this field is widespread indeed.

It is recognized by all investigators that the solution to the prediction problem must come about through a successive narrowing of the limits of prediction. At present, something can be said about the expected occurrence of earthquakes in certain areas in say a 100 year interval. As more knowledge is accumulated, the time interval for which significant statements can be made will decrease. It is evident that at some stage in this process, when this interval has perhaps shrunk to days, a very significant change will occur in the economics of earthquake resistant design, and this will be the point at which the earthquake engineer may find his procedures considerably modified. It seems to be the current concensus of opinion that success in prediction will come about not through some spectacular breakthrough involving a specific technique, but rather through bringing to bear on the problem all of the resources of modern geophysical research. This inevitably means not only major increases in research effort in all branches of geophysics, but carries with it the promise of innumerable side benefits as knowledge in all areas is increased. This is indeed an exciting prospect for all seismologists and earthquake engineers.

In concluding this summary of the Theme III papers, attention may again be directed to the fortunate way in which the various contributions have comprehensively covered so many important aspects of seismology and earthquake engineering. The reporter wishes to express his best thanks to all of these contributors, who have made such successful efforts to present to the conference the results of their investigations.