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Visit to Fourth World Conference on Earthquake Engineering and Seismological Institutions in North and South America, held at Santiago, Chile, January/February, 1969

by

D. Denham

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VISIT TO FOURTH WORLD CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGICAL INSTITUTIONS IN NORTH AND SOUTH AMERICA, HELD AT SANTIAGO, CHILE JANUARY/FEBRUARY, 1969

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The author attended the Fourth World Conference on Earthquake Engineering which was held at Santiago, Chile, from 13th–18th January 1969. The Conference sessions covered most of the wide range of subjects now encompassed by the term 'earthquake engineering'. Notable advances have recently been made in the fields of seismicity, simulated earthquakes, and the study of the elastic response of structures. There is still much to be learnt in the analysis of the inelastic response of structures and the problems associated with foundation and soil structure interactions.

Perhaps the most serious gap is the lack of suitable strong motion records. Despite the large number of accelerographs that have recently been installed, many engineers are still using the 1940 El Centro record because no other suitable strong motion records have been produced. This lack of data has led to the development of synthetic accelerograms which have questionable similarity to real earthquakes.

After the conference I visited the following seismological institutions: the Observatorio San Calixto, La Paz, Bolivia; the Seismology Division of the U.S. Department of Commerce, Rockville, Maryland; Carnegie Institution, Department of Terrestrial Magnetism, Washington, D.C.; the National Standards Laboratory, Washington, D.C.; and the California Institute of Technology, Pasadena, California.

At the Department of Terrestrial Magnetism (DTM) I worked for about two weeks on the problems of locating earthquakes using small networks of stations and adapted a computer programme developed by the staff of DTM for use in the New Guinea region.

1. INTRODUCTION

The task of concisely reviewing the proceedings of the Fourth World Conference on Earthquake Engineering, held at Santiago, Chile, January 1969, and describing the work carried out at the different seismological institutions visited after the conference, is fraught with difficulties. Apart from deciding how brief the reviews and descriptions should be, it is often difficult to emphasize the most important items and it is easy to give undue weight to items of secondary importance.

This was particularly difficult at the conference, where it was only possible to attend about half the sessions because different sessions were held simultaneously. I have therefore given resumes only of the sessions I attended and will leave the assessments of the remaining sessions to the reader when the full proceedings become available.

The visits to the seismological institutions were of great value except the one at Lima. The Seismological Center there was rather disorganized and no benefit was gained from the visit.

The most valuable visit after the conference was to the Department of Terrestrial Magnetism in Washington D.C., where I was able to devote most of my time to the calculation of hypocentres of New Guinea earthquakes. It was refreshing to work in an institution unfettered by administrative duties. The help and co-operation of the officers there, particularly Drs Sacks and James, who gave valuable assistance, was most appreciated.

The record gives a chronological account of my visit and concludes with a section containing some recommendations.

2. THE FOURTH WORLD CONFERENCE ON EARTHQUAKE ENGINEERING. SANTIAGO, CHILE, 13th-19th JANUARY 1969

The Fourth World Conference on Earthquake Engineering, held at Santiago, Chile, was attended by 380 delegates from 29 countries. The investment in civil engineering projects throughout the world is now so great that, wherever very large buildings are constructed, earthquake risk is usually considered, even if the designs are not specially modified to cope with the additional forces due to earthquakes, and even if the buildings are sited in non-seismic zones. As a result the interest in earthquake engineering is now world-wide and even such non-seismic countries as Finland and the United Kingdom sent representatives to the conference.

After the welcoming session, which was addressed by: the Chairman of the Organizing Committee, Professor Rodrigo Flores; the Chilean Minister for Public Works and Transport, Mr S.O. Pretot; and the President of the International Association for Earthquake Engineering, Mr J.E. Rinne, the conference was divided into 14 working sessions.

Throughout the conference two sessions were held similtaneously and it was therefore possible to listen to only about half the papers presented. Appendix 1 lists the official programme, and Appendix II the titles of the papers presented. I will endeavour to abstract the most important points that were covered in the sessions directly relating to the earthquake engineering work of interest to the Bureau of Mineral Resources.

Session J-2; Observations on recent earthquakes

Between the 3rd World Conference, which was held in New Zealand in 1965, and the conference in 1969, no very large disastrous earthquakes occurred. Nevertheless, considerable damage was caused by earthquakes in the period, and the results of several earthquakes were discussed. Most of the loss of life in this period occurred in the region of Iran, Turkey, Greece, and Yugoslavia. Although not in the most seismically active part of the world, earthquakes here usually cause considerable damage because they are mostly very shallow, and because most of the village dwellings are built of dry rubble, stone masonry, and adobe bricks, invariably with heavy earth roofs. Excluding the Iranian and Turkish earthquakes of 1968 it is estimated that, during the period 1965-1967, earthquakes in Yugoslavia, Greece, and Turkey destroyed over 300,000 houses and damaged another 30,000, killing at least 2,600 people.

Although each of these earthquakes had its own characteristics and unusual features, two important conclusions could be deduced which apply to all of them. The first and perhaps most important observation was that an intensity value cannot be meaningfully assessed in areas of earthquake damage. If any assessment is made it cannot be used for design purposes. Most intensity values are found to be too dependent on subjective evaluation; also the effects of pre-shocks and after-shocks usually tend to give higher values of intensity for the main shock because the damage is frequently cumulative.

The actual damage caused results from a combination of the ground motion and the building response. During an earthquake the ground motion varies considerably over small distances and it may not be elastic. The damage may well depend upon the duration of the shaking as well as the peak acceleration value reached. No single number, such as a value of intensity, can properly describe the ground motion during an earthquake.

The second observation was that proximity to a fault break is not a criterion for heavier damage and that serious exception should be taken to empirical formulae connecting properties of the ground and ground movement with intensity.

Two unusual earthquakes occurred near the Konya Dam, India, on 13th September and 11th December 1967. These took place in a region known for its seismic stability: previous earthquakes in the region in historical times have been small and infrequent. The occurrence of these large damaging earthquakes (particularly the one on the 11th December 1967) gave support to the theory that the additional water load on the crust, resulting from the dam's being filled with water, triggered the earthquakes.

If this assumption is correct, then available data show that the triggering is more likely to occur in a relatively quiescent rather than in a seismically active region. For example the sites of Marathon and Kremasta in Greece are located in the least seismic regions of the country. The same applies to Konya in India, Kariba in Rhodesia, Boulder in the U.S.A., and the Contra dam in Switzerland. In contrast, reservoir areas in seismically active regions such as the Benmore site in New Zealand and other sites in Japan and India have experienced no conspicuous increase of seismicity with impounding. If the Upper Ramu dam is to be constructed in New Guinea it will be interesting to observe if any change in seismicity of the region results, although in a highly seismic area this is more difficult to observe than in a non-seismic area.

The most widely discussed earthquake was that which took place near Caracas, Venezuela, on 29th July 1967. It caused nearly 300 deaths, 2,000 injuries, and an estimated damage of $US100 million. The earthquake is one of the most important in recent years, because of its proximity to a city containing many large modern buildings. The Caracas area contains over 1000 buildings with heights ranging from 10 to 20 storeys. Nearly all are variations on the same theme of a slender reinforced concrete frame with non-structural panels of hollow ceramic brick. Although these panels were not taken into account during the design of the reinforced concrete frames, they often exerted a dramatic and usually detrimental effect on the performance of the buildings by adding great rigidity to the upper floors. This left the first storey columns to bear most of the overturning moments and also most of the vertical forces.

Pronounced microzoning effects were observed. The tall buildings in one city area were severely damaged while there was no damage to very similar buildings in nearby regions.

In areas where the alluvium was of moderate depth buildings only a few storeys high were attacked more severely than the taller buildings. In the areas of deep alluvium in Caracas City only the Tall buildings were damaged.

These observations show that the ground - building interaction is of vital importance and undesirable resonances may well be set up in some cases between the alluvium layer and the building. One of the most embarassing revelations at Caracas was that not one accelerograph in the whole region was in operational order when the earthquake struck. This indicates most definitely the need to maintain strong motion instruments properly by making regular field visits to check the equipment.

Session A-1. Seismicity and simulated earthquakes

In this session eight papers were presented on seismicity problems, and six on simulated earthquakes. The approach to seismicity and zoning is now well established and most of the papers were based on the following three assumptions:

1. The maximum acceleration recorded at any one site is a function of the magnitude of the earthquake and the distance from the hypocentre to the recording station. A convenient functional form for peak ground acceleration is:

$$Y = b_1 e.^{b_2 M} R^{-b_3} \qquad \text{--------------------}(1)$$

where b_1 b_2 and b_3 are constants, Y is the peak ground acceleration, and R the distance from the focus. Similar formulae can be used for velocity and displacement.

2. Timewise, the occurrences of large earthquakes in a specified volume is approximately a Poisson process.

3. The well known frequency of occurrence relationship

$$\log_{10} N = a - bM \text{ ------------------------------------(2)}$$

holds for any one area (N is the number of earthquakes occurring with magnitude M or greater, and a and b are constants).

One important result of analyses based on these assumptions is that the more numerous smaller earthquakes contribute more to the risk than the very large, more infrequent earthquakes. The risk from events like the Chilean earthquakes of 1960 and the Alaskan earthquake of 1964 is therefore smaller than the risk resulting from the Skopje and Agadir type shocks, because there are so many more events of this size.

New seismicity maps were presented for Japan, U.S.A., Chile, and Canada and attempts are now being made to estimate actual accelerations rather than to present just Modified Mercalli intensity values. In spite of its many drawbacks, the Modified Mercalli intensity scale is still widely used, because there are still not enough strong motion records from large earthquakes to develop satisfactory estimates for the constants b_1, b_2, and b_3 in formula (1).

The one major advance described in this session was the development of techniques which use simulated earthquake motions suitable for design calculations.

In the earthquake resistant design of important structures it is not uncommon for a digital computer analysis to be made of the response of the structure to a prescribed base acceleration. Recorded earthquake accelerograms are often used for this purpose even though these might not have completely suitable properties. For example, the El Centro 1940 accelerogram has been used all over the world even though its special character may not be really applicable. Because of the rarity of strong earthquakes, the localized extent of the really strong ground shaking, and the seeming proclivity of earthquakes to occur in uninstrumented areas, there are wide gaps in the present-day collection of strong-motion accelerograms. The most significant gap is that the shaking in the vicinity of a truly great earthquake (Richter magnitude 8) has never been recorded. The records that have been obtained close to magnitude 7 events indicate that the duration and frequency content of these earthquakes are extremely variable. It is clear that it will be many years before a suitable collection of different types of records can be assembled. As a result, research workers have generated ensembles of simulated earthquakes by various means to help fill the gaps in the recorded data. The models for these simulated motions are deduced from examination of the statistical properties of recorded accelerograms, the most significant of which are the duration, intensity, and frequency content of the motion.

Mathematical models of varying complexity have been used or suggested to simulate accelerograms. These models include white noise, stationary gaussian processes, and nonstationary processes of various kinds.

A common method of producing the required record has been to multiply a stationary process by a time-dependent envelope. Usually the envelope consists of three parts: (a) a rapid build up of intensity from zero (often a quadratic function); (b) a constant central portion; and (c) an exponentially decaying tail. This envelope is then multiplied by a filtered Poisson function. Sometimes it is desirable to introduce some time-dependent pass-band filtering into the generation process. This can be done by simply altering the time scale in an appropriate manner.

Once in a digital form the records can be filtered, scaled, and processed in a required manner. Usually the simulated earthquakes are reasonably representative of the type of motions modelled and they are now being used by engineers in the United States.

Session A-2. Ground motions and instruments

This session was rather disappointing. Apart from a good review paper on instrumentation by Hudson of Caltech and an interesting presentation of some recent accelerograms by Cloud and Perez of USCGS, most of the papers were mathematical analyses of ground response for different earthquakes and different elastic and geometrical parameters of the ground, and these did not have direct practical application.

The paper by Cloud and Perez displayed ten strong motion records obtained by the USCGS in the last four years. Plate 1 is a copy of their diagram showing the maximum accelerations recorded by their network of instruments (Cloud & Perez, 1969). The high acceleration recorded at Lima, Peru, 100 miles or so from the epicentre (point 17) may be less anomalous than indicated in the figure. It seems likely that faulting proceeded southward from the epicentre along an offshore fault, so that the energy source for Lima was a closer point on the fault, much nearer to Lima than the epicentre - although the S-P time from the accelerogram does not support this hypothesis.

The plot shown in Plate 1 gives a good rule of thumb answer to the value of the maximum acceleration likely to be recorded at any one place resulting from a large earthquake a certain distance away. This is the type of information which will be used when seismic zones are allocated.

Session A-3. Elastic response of structures

Although this session was devoted almost entirely to engineering problems it contained many interesting papers on the state of the art in analysing the dynamic response of buildings to particular ground motion. Japanese and American engineers have developed elaborate computer programs to calculate building responses and for large high-rise structures the analysis seems to be extremely thorough. In some cases the calculations are checked by vibrating the building before occupation and checking these results against those predicted from the drawing board models.

In the examples presented to the Conference the agreement was almost too good to be true. This indicates that given enough time and money - and a big fast computer - the problems of the elastic response of buildings can be solved.

The only disturbing item was the lack of variety of suitable ground motion inputs. In many cases only the 1940 El Centro record is used and there the analysis ends. It is clear that more real accelerograms are badly needed to complete this kind of analysis. This need is no greater anywhere than in New Guinea, where Californian records are still being used as standards for ground response calculations.

Session A-4 Inelastic response of structures

The previous session dealing with the elastic response of structures illustrated how well the state of the art has progressed in that field. This session dealing with the inelastic response of buildings, i.e. behaviour after their elastic limits have been exceeded, showed that this part of the problem has not nearly been solved. There are many reasons why this is so. In the first place there are many more variable factors to be studied, secondly it is usually impossible to test experimentally the results of the calculation, and thirdly the ductility factors are not as well known as the elastic parameters.

Clearly the inelastic response is most important, for this is the stage before failure and collapse. Some progress has been made but the field is still very open for large improvements to be made.

Session A-5. Soil and soil structures

This subject is very important. A large amount of earthquake damage is caused by changes in the elastic properties of the soil due to earthquake vibrations. The tectonic subsidence at Valdivia, Chile, in 1960, Anchorage, Alaska, 1964, and Niigata, Japan, 1964, emphasizes these effects most dramatically. The problem has been attacked in two ways. The first method is to measure the elastic properties of the material under examination before and after shaking. This test can be done in a number of ways while the material is saturated, unsaturated, stressed, unstressed, etc.

The second method is to analyse the problem mathematically. This involves setting up a suitable mathematical model, calculating such things as the stresses in the soil and the pore-water pressures and then seeing how these factors are modified during vibration. In recent years these problems have become very important because of the large number of earthdams being constructed throughout the world. It is essential to know how these will respond to an earthquake.

Session A-6. Foundation and soil structure interaction

The subjects discussed in this session follow on naturally from those covered in session A-5. This was perhaps the most difficult of all subjects covered at the whole of the conference.

Experimentally it is difficult because it is necessary to wait for an earthquake, to see what happens when the whole ground is strongly vibrated. Furthermore the elastic properties of soils are usually too inhomogeneous, particularly near the surface, to be able to apply any manageable mathematical models which in any way closely respond to the real case. The best approach here seems to be by examining closely the soil-structure interaction in a real earthquake and drawing conclusions from accurate observations.

Session B-5. Design criteria and research

In many ways this was one of the most interesting sessions of the whole conference. It covered important and unusual aspects of earthquake engineering which could not be properly accommodated elsewhere in the conference.

Reviews of research work currently under way in the U.S. were given. Perhaps the most interesting (and costly) development is the investment in big shaking tables.

The University of Illinois, the University of California, and the Japanese have built quite large simulators designed to test the response of buildings. The main idea behind these projects is to construct a building on a shake table and observe the response of the building to known inputs at the base of the unit.

The Illinois simulator is an experimental facility designed to subject small-scale structures to vibratory base motions of a regular or random character in a horizontal direction. The test platform is only 12 feet square and can support test specimens weighing only up to 10,000 lbs. However, it permits a double-amplitude displacement of 4 inches and a maximum acceleration of 7.5g at 100 Hz. Preliminary tests using the system have indicated that it is possible to generate 'random' motions of the platform with resulting spectra similar to those produced by measured earthquake motions.

The Japanese have constructed a device that will horizontally vibrate a five storey building by means of 20 oil jacks each with a capacity of 50 tons. These operate on the side wall of the building and the overall loading capacity is 100 tons.

Not to be outshaken, the University of California is planning to build (at a cost of about $20 million) a 100 feet square shake table on which they will construct a 3 story reinforced concrete building which can be shaken to destruction. The shaking table alone will weigh 1,000 tons and the building will weigh about 2000 tons. To drive this 20 horizontal actuators and 12 vertical actuators will be used. These will enable forces up to 2/3g to be generated. The cost of such an undertaking and the power needed to operate the machine is fantastic, but perhaps in a country that spends $3,000 million every year on buildings in the earthquake prone states, a mere $20 million to shake a building to destruction in a controlled manner is good value for money.

Session J-4. Special papers

The final meeting was a plenary session devoted to special papers presented by distinguished scientists attending the conference, and an address by Housner (of Caltech), the new President of the Association.

Housner's address was a fitting climax to the conference. He gave a masterly review of the present state of the art and indicated where he though the future efforts should be made. On the whole he thinks that the earthquake risk is probably more serious now than ever before, because there are many more people living in earthquake zones and there are many more large buildings. In the earthquake zone of the U.S. alone it is estimated that $3,000 million is being invested in new buildings each year. To this should be added expenditure in Japan, Eastern Europe, and South America. The main aim of the engineers should be to avoid collapse in an earthquake. In a major earthquake we must expect some damage and the answer is to strike the right cost risk ratio. This will lie somewhere between zero and complete protection.

At present, it is not known how far most buildings are from the collapse point. What is urgently required is a full understanding of the ground and building motion, and the collapse mechanism. To this end further work must be done in the design of structures and in the recording of ground motion.

Furthermore there is the problem of special structures like nuclear reactors, large earth dams, and suspension bridges. As yet none of these types of structure has been subjected to strong ground motion. It is most important that they do not fail in a strong earthquake.

3. OBSERVATORIO, SAN CALIXTO, LA PAZ, BOLIVIA 19-22nd JANUARY, 1969

The observatory at San Calixto in La Paz is one of the oldest established observatories in South America. Continuous seismological recordings have been made there since 1912, when the Wiechert seismographs, which are still operating at the town site in La Paz, were set up by Fr. Descotes. This was one of the key stations in the early seismological studies of the South American region. The timing was extremely reliable because clock corrections were obtained by direct astronomical observations carried out at the same site. All the old seismograms are readily available for inspection and they serve as an invaluable source of early records.

Fr. Descotes acted as director of the observatory until 1958 when he was replaced by the present director, Fr. Ramon Cabre. In 1965 a sub-director, Fr. Louis Fernandez, was appointed. In the last few years, the activities of the observatory have grown considerably. A World Wide Standard Seismograph station (LPB), situated on compact clay in a small canyon, was opened in 1962 on the outskirts of La Paz. The magnifications of the short period and long period seismographs are 50K and 3K respectively, which are not as high as might be expected in a quiet inland region. The clay foundations probably increase the signal to noise ratio and may not provide good coupling to the bedrock.

The main instrumentation under the observatory's control is situated at Penas (PNS). This is about 60 km from La Paz near the road to Lake Titicaca. With financial support from the U.S. Navy, a twelve element seismometer array and a four unit infrasonic array are operated on the high flat Altiplano. Plate 2 shows the approximate dimensions of these arrays. The seismological array consists of 7 short-period vertical Johnson-Matheson seismometers, 2 short-period horizontal seismometers of the same make and a three component long-period set of instruments similar to those incorporated in the World Wide Standard Seismograph System.

Amplification is provided by photo-tube amplifiers and the control console is similar to that used in the WWSSS. The background noise is much lower at Penas than at La Paz and the magnification of the short-period instruments is 500K at 3 Hz and 3000K at 1 Hz. The long-period seismographs operate with a maximum magnification of 30K at 24 second period.

The signals are recorded on a 16 mm develocorder, which automatically records an develops the film, and a 35 mm film recorder which is usually used only when additional data are required for detailed analyses. Time marks of 150 ms duration are put on the film every ten seconds and the final trace is recorded at about 150 mm/min. The calibration is controlled by a Hewlett Packard low frequency oscillator and the usual step impulse from the control console.

The Penas infrasonic array was set up in parallel with the seismic array and the four infrasonic detectors are situated very close to the seismometers. Plate 2 shows the locations of the infrasonic detectors. Each detector consists of a very sensitive capacity microphone coupled to a tube 300 m long with sealed ends and capillary inlets every 5 m, to filter out undesirable high frequency turbulence. These instruments are sensitive to pressure changes as small as 1/10 microbar. One of the problems of setting up the detectors is that of ensuring that their temperatures remain very stable. This is accomplished by burying the microphones and surrounding them by additional heat-insulating material.

The outputs from the four elements are passed through two sets of filters. One set passes high frequency variations with the 3db points situated at 1 and 10 sec and a maximum sensitivity on the recorder of 1.0mm dyn^{-1} cm^{-2} at 4 sec period. The other set of filters enhances the long period variations and the 3db points are at 60 and 300 sec. The maximum sensitivity on the recorder is about 0.1 mm dyn^{-1} cm^{-2} at about 150 sec period. As well as these recorders, which show the changes in pressure, each channel is integrated to give a measure of the changes in energy level. The integrated traces often give better signal-to-noise ratios for discrete events such as atmospheric nuclear tests and they are the most useful records for rapid investigations. The pen recorders are supplemented by a six channel tape recorder which records the signals through a broad pass-band. The tapes are sent to the National Standards Laboratory in Washington D.C. for analysis.

The main use of the infrasonic equipment is for detecting small changes in atmospheric pressure due to such things as volcanic eruptions, atmospheric nuclear tests, and large earthquakes. Examples of each type of these phenomena, recorded by the array, are available at the central observatory in La Paz. I was impressed by the sensitivity and resolution of the array and considered the possibility of establishing a similar system in New Guinea. There are at present no infrasonic arrays in Australia, and New Guinea would be a good place to operate one because it is close to an area of active volcanoes, it is almost midway between the Chinese and the French atomic test sites, and is also in an area of high earthquake activity.

Apart from the sites at Penas and La Paz, the observatory operates a network of four outstations in Bolivia at Tarija, Cochabamba, Sicasica, and Riberalta. These are single vertical component stations except for the one at Riberalta, which is operated for the Carnegie Institution of Washington and has been specially designed to record the deep South-American earthquakes which occur nearby. During my visit, investigations were made to find a site for a seismic station at San Miguel in the eastern part of the country. The problems of operating seismic stations anywhere in Bolivia are formidable. Communications are very poor, most of the remote villages are very primitive, and it was my impression that the difficulties are worse than those encountered in New Guinea.

In the central office at La Paz a number of research projects was being undertaken under the direction of Fr. Fernandez. These include travel-time studies, first motion studies, crustal studies from P wave spectra- using both long and short-period records - and investigations into the results obtained from the infrasonic array. The main office in La Paz was well equipped with a good library, a digitizer, and an IBM card punch, and the staff have ready access to an IBM 1130 in La Paz. I was most impressed by the work carried out there and particularly by the competent supervision given by Fr. Fernandez.

4. CENTRO REGIONAL DE SISMOLIGIA PARA LA AMERICA DEL SUR, LIMA, 22-23rd JANUARY, 1969

The South American Seismological Centre in Lima, Peru, has been established, under the auspices of UNESCO, for about three years. The aims of the institution appear to be rather vague. At one stage it was hoped that the centre could operate a large seismic array near Brasilia, in Brazil, but shortage of funds and the lack of interest from the Brazilian Government successfully foiled this proposal. At present the main work consists of the preparation of a seismological bulletin containing all the readings obtained at all the South American seismic stations. There are no computing facilities at the centre and no determinations or revisions of hypocentres are carried out.

During my visit the Associate Director of the Institution, Dr Garjardo, was absent in Chile, and only one seismologist was working in the office. My impression was that without a large influx of funds the function of the centre will not be very significant. It would probably be better to try and develop stronger national organizations at this stage of the development of seismology in South America, rather than build up a supranational institution.

While in Lima I was able to visit the local standard seismic station at Nana (NNA). This is situated about 25 km from Lima in the foothills of the Andes and is operated by the Seismological Division of the Instituto Geofisico del Peru. The vault contains a World Wide Standard Seismograph System which was installed in 1962. The magnification of the short and long period seismographs are 50K and 3K respectively. Additional equipment installed in the vault consists of a Benioff tensionometer and a 100 sec period mercury pendulum. These are to observe the very long-period earth movements due to earth tides, free oscillations of the earth, and very long-period surface waves.

5. CARNEGIE INSTITUTION OF WASHINGTON, DEPARTMENT OF TERRESTRIAL MAGNETISM, 30th JANUARY - 11th FEBRUARY, 1969

During my 18-day stay in Washington I was based at the Department of Terrestrial Magnetism and was able to use their office space, library, computing and other facilities, including unrestricted access to their IBM 1130 computer. The Department is a rather unique scientific organization. It employs only about 20 professional officers and although it is limited to a fixed annual income of about $3/4 million, it is free to spend this money how and when it pleases. Under its present Director, Dr Ellis T. Bolton, basic research is being carried out in three main scientific disciplines: astrophysics, biophysics, and geophysics.

I was concerned only with the geophysics group and will give a brief description of the work carried out by this section before describing my own activities there. The resident group consists of Dr Aldrich (the Assistant Director DTM), Dr Sacks and Dr James. Visiting DTM during my stay were Fr. Saa, a Carnegie research fellow from Antofagasta, Chile, and Dr Linde, on leave from Queensland University, Australia.

Earthquake seismology

Much of the basic data used in the seismological studies at DTM comes from their own stations which have been set up around the Pacific. At present they have two stations in Japan, one in Papua, and a network of stations in Bolivia and Peru. Some of these instruments record broad band seismic signals on magnetic tape which can be played back in Washington at appropriate gain and filter settings. Most of the basic work carried out at DTM on attenuation in the earth's mantle has used these results. The remaining stations have short-period single component seismographs recording with pen and ink on two day drums.

Focal mechanism studies

Continuing some preliminary work carried out at Brisbane, Dr Linde is studying, under the supervision of Dr Sacks, the focal mechanisms of earthquakes. At the time of my visit he was concerned with reviewing recent literature. Later he hopes to analyse some recordings made with DTM equipment, close to earthquake sources. This work could be crucial in examining some of the predictions made by proponents of the new global tectonics. (Isacks, Oliver, & Sykes, 1968) and may well provide definite evidence relating to basic tectonic processes.

Explosion seismology

DTM has, for some years, been interested in explosion seismology and was a major participant in the Lake Superior experiment. Their latest project was in the Bolivian and Peruvian Andes, where they took part in a combined explosion programme with the Southwest Center for Advanced Studies at Dallas, Michigan University, and numerous South American institutions. Work is currently underway interpreting these results.

Model work

The Department is in the process of establishing a model laboratory to study seismic wave propagation under experimental conditions. In this way they hope to examine the effects on wave propagation of mountain roots, velocity gradients, and partial melting. This work is being carried out by Dr James. The main problem appears to be that of obtaining suitable materials which simulate a scaled down real earth. The rewards from these experiments could be great, if the scaling problems can be solved.

Core phases

One of the most important studies being undertaken is that the Fr. Saa on core phases. Working under the direction of Dr Sacks, he is using records from high gain South American stations to analyse core phases recorded from large earthquakes in the western Pacific region. These stations are favourably situated to record core phases from all the western Pacific arc regions such as the Banda Sea, the Marianas, and Japan.

In spite of the tremendous effort that has been put into the study of the travel times of early phases in recent years (Adams & Randall, 1964; Bolt, 1964; Ergin, 1967), and the accurate values of dt/d which have been obtained from the large seismic arrays, there is still no satisfactory core model which explains all the observations. In particular the amplitude variations associated with the GH branch are very difficult to explain. Before the caustic at about 145° the amplitude of the GH branch is very small but after the caustic it is supposedly large; however, timewise it cannot easily be distinguished from the BC branch, and in fact it is becoming increasingly doubtful whether or not the GH branch actually can be observed past the caustic. It may really be only the BC branch that is seen in this region of the time-distance curve.

Instead of working with actual travel times all the points are being picked relative to the DF branch. This eliminates station corrections and uncertainties in hypocentre depth. Amplitude studies can be carried out in a similar way by comparing the amplitudes of the other core phases with that of the DF branch.

Hypocentral locations

A major contribution made by the DTM in recent years has been the study of the location of local earthquakes. Although the U.S. Coast and Geodetic Survey and the International Seismological Centre have been publishing earthquake hypocentres for a number of years, there are two main problems in this work which are often overlooked. The first arises because of the basic mathematical instability in the four parameter least-square hypocentre solution, because the four variables - origin time T_o, focal depth h, latitude 0, and longitude Ø are not strictly independent. Specifically the variables representing the origin time and the depth of the shock are strongly interdependent and the values of these two parameters can be readily traded to give different solutions with similar overall residual errors.

The second problem arises from the fundamental properties of the travel times within the earth. Low values of dT/dh for P waves at certain epicentral distances introduce a large uncertainty in focal depth. These problems became very evident when the origin times published by USCGS for some South American earthquakes were computed to be later than reliable P wave readings of the same shock recorded at some of the local DTM stations.

Accordingly a method was developed to improve the hypocentral locations of local shocks (for large teleseisms, pP and pPKP can sometimes be used to fix h, and reduce the problem to one of three variables). The method consists of computing the origin times independently for each station and obtaining a mean T_o which can be used to eliminate the other three variables (h,λ, and 0). This procedure eliminates the mathematical instability in the general four parameter least squares method, but the problem of low (dT/dh) cannot be overcome except by good station distribution. Plate 3 (taken from James et al., 1969) shows a plot of a function (dT/dz) where dT is the arrival time difference in seconds for a depth change dz of 63 Km, and it shows how, for earthquakes occurring shallower than about 100 km and at epicentral distances of 2-5 degrees, the depth resolution is very poor. This is a fundamental problem associated with the seismic wave travel-times and no sophisticated mathematical analysis can overcome it. The only solution is to have stations nearer than about one degree to the epicentre.

While I was at DTM I was able to use the programmes developed by James and Sacks to analyse New Guinea Earthquakes recorded by the Rabaul and Port Moresby networks for the months of September, October, and November, 1968. It was found that, with the increase in the number of local seismic stations in recent years, it was possible to locate, independently, nearly all the earthquakes listed by USCGS in their PDE sheets as well as a good many more besides. For example in September, 1968 USCGS listed 48 shocks for the New Guinea region; all but 6 of these were accurately located by the DTM programme. In addition a further 25 earthquakes were located, which were not listed by USCGS. One reason for this is that some of the Rabaul outstations are very remote and frequently the results from these locations are not received at USCGS in time to be used in their computations. It is therefore recommended that all local earthquakes be re-examined wherever possible to try and obtain more accurate hypocentres and to increase the number of accurately located earthquakes.

Three interesting facts emerged from this study. The first was the consistency of the results obtained from the Lae, Goroka, and Port Moresby stations. When P and S arrival times were available from these stations it was found that the origin times usually agreed within two seconds. This gives confidence in the hypocentral solution and reassurance to the seismogram readers picking S phases. The Lae, Goroka, and Port Moresby stations were therefore found to be very effective, particularly for shocks from the New Guinea mainland.

The second fact, which was rather surprising, was the effect of the Rabaul Harbour network on the solutions. Although these stations are very close together, with time differences across the array seldom exceeding one second, they appeared to give appreciable stability to the solutions. Despite the small aperture of the array it was almost invariably better to include all the Harbour network stations in the solution than to use just one or two stations.

The third fact revealed by the study was that the Rabaul stations Agenahambo and Tabele are not very reliable. Sometimes the times published in the bulletins were out by a minute and even when the time seemed correct they frequently gave very high residuals. The reasons for this are not clear but in all future work results from these two stations should be analysed with great care.

During my stay I was able to obtain card decks of all the hypocentral programmes used at DTM and hope to use some of these on the IBM 1130 at Port Moresby.

6. SEISMOLOGY DIVISION U.S. DEPARTMENT OF COMMERCE, JANUARY 27-28th 1969

One and a half days were spent at the Coast and Geodetic Survey's Seismology Division at Rockville, Maryland.

Much of the seismological work done by USCGS is carried out here, but there are regional centres in other parts of the U.S. For example the strong motion work is done in San Francisco, the Data Center is at Asheville, North Carolina, the main instrument centre is at Albuquerque, New Mexico, and there is a research centre at Menlo Park, California. After an introduction by Mr Leonard Murphy, the chief of the Seismology Division, discussions were held with nine other officers about various aspects of their work.

The main operation of the centre is the determination of earthquake hypocentres on a world-wide basis and publication of these results. The first arrival times of earthquakes from a large number of stations throughout the world are transmitted to Washington to be used in the computations. I was surprised by the large amount of subjective control exercised by the geophysicists in the publishing of the hypocentre solutions. Frequently they may constrain the depth of a solution or make subjective decisions that affect which solution is published. This personal supervision breaks down on occasion; for example, solutions are sometimes published that have been determined by using just the Rabaul harbour network and one other station (usually PMG or HNR). This may give some sort of solution but the poor geometrical distribution of stations does not make the result very accurate. On the whole the operation appeared to work very efficiently.

Discussions were held with Dr J. Lander on hypocentrology, Mr W. Thickey and Mr J. Devine on ground motion resulting from engineering vibrations, Dr R. Eppley on Tsunamis, Dr E. Engdahl on core phases, Mr. J. Jordan on explosion seismology, Dr R. Brazee on felt intensity data, and Mr R. McCarthy on the Data Center.

I investigated prices for complete sets of 70 mm chips of copies of seismograms from the standard network. The annual bill amounts to about $US8250. It is not recommended that the BMR invest to this extent although it may be worthwhile to obtain all the copies of the large New Guinean and Australian shocks, on a routine basis. With R. McCarthy, I confirmed that the data centre still had the original 1962 Port Moresby seismograms and made arrangements for these to be shipped back to New Guinea.

One of the most impressive members of the USCGS staff was R. Engdahl, who has done a great deal of work on core phases. He has just completed his thesis entitled "Core Phases and the Earth's Core" and has recently published several papers in which multiply reflected waves within the earth's core such as PKKKP, SKKKP and PKKKKP have been analysed. Surprisingly some of these arrivals have been recognized only recently.

7. NATIONAL STANDARDS LABORATORY, WASHINGTON, JANUARY 29TH, 1969

The infrasonic array which was set up at Penas, Bolivia, was developed at the National Standards Laboratory, Washington, D.C. I took the opportunity to visit this establishment, to investigate the possible future development of the work, and to ascertain whether useful programmes of a similar nature should be introduced in Australia.

The National Standard's officers feel that single station micro-barographs do not provide sufficient data for accurate detection work, because of the high variable background noise present at each station. They feel that an array of at least 4 detectors placed at about 5 km intervals is required so that genuine events can be identified by correlation techniques across the array.

Currently there are only a few infrasonic arrays operating throughout the world. The only one in existence outside the U.S. (excluding possible arrays in the USSR) is at Penas, Bolivia.

The National Standards Laboratory would be willing to provide all the equipment necessary to establish an array, except the tape recorder. For this service they would expect the station to be maintained by local officers and the tapes to be transmitted to Washington at regualr intervals for analysis.

Mr H. Matheson, a pioneer in this work, was keen for an array to be established in Australia. I told him that I did not think the BMR had the staff at present to operate such a system. I also feel that the results obtained are very meagre compared to the effort required to keep the array functioning. At Penas, for example, the infrasonic array appeared to require much more maintenance than the seismic array, yet the results obtained from the seismic array are, at present, much more worthwhile.

My feeling is that BMR should keep itself informed of infrasonic developments so that if a major break-through in this field occurs, it would be possible to take advantage of it. At present little seems to be detected by infrasonic methods that cannot be obtained from other means, except perhaps the detection of atmospheric nuclear tests.

8. CALIFORNIA INSTITUTE OF TECHNOLOGY, 12TH-14TH FEBRUARY 1969

Three days were spent at Pasadena visiting the seismological laboratory and the Division of Engineering and Applied Science.

At the seismological laboratory, which is directed by Dr Don L. Anderson, a comprehensive programme of geophysical research is undertaken in a wide range of fields. The routine seismological work consists of the operation of about 8 stations in southern California and the processing of results from this network. The outputs from these stations are telemetered into the main office and are recorded on pen recorders. Local earthquakes can be accurately located almost immediately using a procedure involving differences in P arrival times at all the stations. The work involved in the operation of this network is only a small portion of the activities undertaken at the laboratory. During my visit the research staff consisted of about eight permanent officers and six students though these numbers appear to be continually changing.

The main effort during my visit seemed to be involved in the study of the composition of the earth's mantle and associated problems. Work is also underway on focal mechanism studies, large faults PKPKP precursors caused by reflections from within the upper mantle, and a study of old earthquakes.

This last study is being undertaken to investigate the level of global seismic activity since the late 19th century. Work by Gutenberg and Richter indicated a large decrease in activity from the turn of the century, and this study is aimed at verifying this result. The technique used involves examining the amplitudes of the 100 second period surface waves from all the very large earthquakes. Records have been obtained from most of the seismological institutions that were operating at that time; these are copied, digitized, and analysed to estimate the magnitude of the earthquake and the energy release.

The computing facilities at Pasadena are extensive: a digital computer, analogue-to-digital converter, and a direct digitizer are available in the office. For a large programme the computer at the computing centre at the main Pasadena Institute is available, and for a small electronic digital computer like the Hewlett Packard 9100A is available in the office. This is a simple computer with four different outlets or control modules. Each can be worked simultaneously, and at a cost of about $1000 an outlet the price is very competitive.

Library facilities are first class and the shelves are well stocked. A complete set of WWSSS 70mm chips are also to hand.

I was most impressed at the communication and idea flow at Pasadena. While I was visiting the Seismological Laboratory there were three seminars all pertaining to the earth science disciplines. The rapid flow of information from institute to institute by frequent travel ensures that ideas are rapidly transmitted to the benefit of all.

One morning was spent at the Division of Engineering and Applied Science of the Pasadena Institute. The permanent staff are Housner, Jennings, and Hudson, three leaders in the field of earthquake engineering, each of whom has made large contributions to the subject. Housner and Jennings work mostly in the field of building response and ground vibrations. Hudson is currently involved with assessing the instrumentation aspects of recording strong ground motion and is also working on the development of a strong motion recorder which will record the signal on magnetic tape. He has to hand, for evaluation, most of the accelerographs commercially available in the western world, and is working closely with the Coast and Geodetic Survey Group in San Francisco headed by Cloud.

9. DISCUSSION AND RECOMMENDATIONS

The work carried out in the field of earthquake engineering at the Port Moresby Geophysical Observatory compares favourably with that undertaken at similar institutions. The recommendations made on the question of seismic zoning in Papua and New Guinea with regard to the Building Regulations appear to be sound. The proposals made by Skinner in his report (BMR 1968/140) should be implemented as soon as possible, in particular the ones relating to the installation of accelerographs and to the creation of a position to be responsible for the earthquake engineering research work carried out in New Guinea.

One of the most striking and perhaps surprising facts to emerge from the 4th World Conference on Earthquake Engineering, was the lack of any up-to-date reliable strong motion records. In fact most of the engineers working on building response to earthquake motion are still using the record written in 1940 at El Centro, California. This position arises mainly because most of the world's accelerographs are installed in the west coast of the United States where the seismicity is relatively low compared to regions such as the Aleutian Arc, Papua-New Guinea, and Japan. By installing accelerographs in New Guinea, particularly in the most active areas, such as the south coast of New Britain, where the majority of the Territory's large shallow earthquakes occur, there is a good chance of obtaining some really worthwhile results in a comparatively short time.

Another factor to be investigated when considering the establishment of a network of accelerographs is that the severity and character of the earthquake attack is strongly influenced by local conditions. It was mainly for this reason that Skinner recommended that at least one instrument be installed in each major Territory town where future building development can be expected. Only in this way can a library of suitable pertinent records be established which engineers can use for their building response calculations.

From the seismological point of view, the study of particle motion obtained from an accelerogram could prove a valuable tool in our understanding of earthquake mechanisms and would provide additional information to the focal mechanism investigations currently being undertaken at Port Moresby.

I therefore strongly recommend that accelerographs be purchased as soon as possible by either BMR the Commonwealth Department of Works, the New Guinea Administration, or possibly all three working in conjunction.

The second main recommendation involves the proposal to create a position in earthquake engineering research.

With the present staffing arrangements at Port Moresby I do not feel we can undertake, on a permanent basis, the operation of the proposed accelerograph network and the processing of the results.

It would appear that the duties of the research fellow would comprise at least the following assignments:

1. Installation of accelerographs.

2. Supervision of the operation of all the strong motion stations in Papua and New Guinea. There is probably more to this than would appear at first sight. It would probably involve station inspections, record changes and battery checks every 3-6 months. In some centres this part of the operations has been ignored with rather disastrous results. For example no strong motion records were obtained of the Caracas earthquake of 1967 simply because of high resistance connections and flat batteries in most of

the instruments.

3. Interpretation of the results. The engineers require eventually a digitized record of the ground motion to use as input data in their building response calculations. However there are other many important aspects to be investigated, for example:

(a) The study of particle motion near large earthquakes.

(b) Derivation of local relationships between the magnitude, depth, and distance of an earthquake and the spectral density of the accelerogram.

(c) Investigation of changes in ground motion with differing ground conditions, (i.e. hard rock, clay, sand, etc).

(d) Establishment of a library of real and synthetic (when appropriate real records are unavailable) accelerograms.

All these projects would offer worthwhile rewards both locally and a world wide basis.

I therefore recommend that a case be prepared as soon as possible for the creation of a research post in earthquake engineering.

The third recommendation arises from the observations made during the post conference visits. It involves the problems of communications. I was most impressed with the rapid transfer of information in all the institutions visited throughout the United States. Reports are produced rapidly for publication and the whole process from the first draft to the published paper takes only a few months. A typical example is the report published in August 1968 and containing a comprehensive account (120 pages) of the Borrego Mountain Earthquake of 9 April 1968 - five months from earthquake to publication, and the report contained many diagrams. Even the San Calixto Observatory in La Paz is able to produce reports with a similar time lag.

I recommend that a thorough investigation be undertaken in Canberra to speed up the publication process so that results can be made available at an early date.

The fourth recommendation concerns future attendance at World Earthquake Engineering Congresses. I found the proceedings extremely valuable and I recommend that BMR should be represented at the next conference (venue not yet decided). I also recommend that both the Public and Commonwealth Department of Works of Papua and New Guinea should send a representative to the next meeting because of the growing importance of earthquake risk to engineering projects in this region.

10. REFERENCES

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APPENDIX I

OFFICIAL PROGRAM

The schedule of meeting of the 4th World Conference on Earthquake Engineering in its final form was:

Monday, 13th January 1969

Morning Session.		Chairmen.
	Registration	
J-1	Welcoming Session	Flores
Afternoon Session		
J-2	Observations in Recent Earthquakes	Steinbrugge.

Tuesday, 14th January 1969

Morning Session.		
A-1	Seismicity and Simulated Earthquakes	Rosenbluth
B-1	Vibration Test of Structures	Esteva
Afternoon Session		
A-2	Ground Motions and Instruments	Okamoto
B-2	Behavior of Structural Elements	S. Arias.

Wednesday, 15th January 1969

Conducted Tour to Valparaiso, Chile's main seaport

Thursday, 16th January 1969

Morning Session.		
A-3	Elastic Response of Structures	Penzein.
B-3	Large Buildings and Structural Details	Muto
Afternoon Session		

Afternoon Session

A-4	Inelastic Response of Structures	Housner
B-4	Design of other Structure	Despeyroux

Friday, 17th January 1969

Morning Session.

A-5	Soils and Soil Structures	Ambrasseys
B-5	Design Criteria and Research	Turner

Afternoon Session

A-6	Foundations and Soil-Structure Interaction	Moore
B-6	Small Buildings, Insurace, Damage Repair.	Krishma

Saturday, 18th January 1969

Morning Session.

J-4	Special Papers	Flores

IAEE Business Meeting.

APPENDIX II

TITLES OF PAPERS PRESENTED AT 4TH WORLD CONFERENCE ON EARTHQUAKE ENGINEERING

Session J-2: Observations in Recent Earthquakes.

Chairman - Karl V. Steinbrugge.
"Observations of damages of industrial firms in Niigata Earthquake", Heki Shibata, Sumiju, Fuji, etc.
"Macroseismic observations from some recent earthquakes", N.N. Ambraseys.
"Structural engineering aspects of the 1967 Adapazari, Turkey, Earthquake", Rifat Yarar, Semih S. Tezcan.
"The Koyna, India, Earthquake", G.V. Berg, Y.C. Das, K.V.G.K. Gakhale, A.V. Setlur.
"Lessons from some recent earthquakes in Latin America", Luis Esteva, Octavio A. Raxcon, Alberto Gutierrez.
"The Caracas Earthquake of July 29, 1967". Venezuelan Official Seismic Commission.
"The July 29, 1967 Venezuela Earthquake. Lessons for the Structural Engineer", Henry J. Degenkolb, Robert D. Hanson.
"Behaviour of tall buildings during the Caracas Earthquake of 1967". J. Ferry Borges, J. Grases, A. Ravera.
"Implications on seismic structural design of the evaluation of damage to the Sheraton-Macuto", M.A. Sozen, N.M. Newmark, G.W. Housner.
"Caracas, Venezuela, Earthquake of July 29, 1967" Diego Ferrer, Lloyd S. Cluff.

Session A-1: Seismicity and Simulated Earthquakes.

Chairman - Emilio Rosenblueth.
E. Rosenblueth, General Report.
L. Esteva, "Seismicity prediction: a Bayesian approach."
C.A. Cornell et al, "The major influence on seismic risk".
C.W. Housner, "Probability of ground shaking and estimates of maximum magnitude".
W.G. Milne and A.G. Davenport, "Earthquake probability".
C. Lomnitz, "An earthquake risk map of Chile".
S.T. Algermissen, "Seismic risk studies in the U.S."
H. Goto and H. Kameda, "Statistical inference of the future ground motion".

J.B. Rothe, "Earthquakes and reservoir loadings".
Q.A. Rascon and C.A. Cornell, "A physically based model to simulate strong earthquakes on firm ground"
P.C. Jennings, G. Housner, and N.G. Tsai. "Simulated earthquake motions for design purposes.
M. Amin et al, "Significance of nonstationarity of earthquake motions".
H. Coto and K. Toki, "Structural response to nonstationary random excitation".
E. Rosenblueth and J. Elourdy, "Responses of linear systems to certain transient disturbances."
J. Menzein and S.C. Liu, "Nondeterministic analysis of nonlinear structures subjected to earthquake excitations".

Session B-1: Vibration Tests of Structures.

Chairman - Luis Esteva
Luis Esteva, General Report.
Yotsuki et al, "Summarized report of dynamic rests of high rise buildings in Japan".
Juan S. Carmona, "Periods of buildings of Mendoza City".
H. Sandi, "Experimental results of the dynamic deformities of multistorey buildings".
Y. Osawa et al, "Earthquake measurements in and around a reinforced concrete building".
N. Nielsen, "Dynamic response of a 90 ft steel frame tower."
Issago Funahashi, "Vibration tests and test to failure of a 7-storey building".
Sh. G. Napetraridze, "Use of resonance method in mechanical modelling of seismic effect on structures."
D.V. Mallick, "Resonance testing of multistorey infilled frames."
S.V. Polyakov et al, "Investigations into earthquake resistance of large panel buildings."
Chikaaki Ueda, "Study on the large scale displacement vibration tests."
T. Takahashi, "Vibration studies of an arch dam".
Shunzo Okamoto, "A method of dynamic model test of arch dam".
E. Kuribayashi, "observed earthquake responses of bridges."

Session A-2: Ground Motion and Instruments.

Chairman - William K. Cloud.
William K. Cloud and Virgilio Perez, strong motion-records and acceleration".
Kiyashi Kanai, "On the earthquake motions for aseismic designing".

S. Yoshikawa, M. Shima and R. Irikura, "experimental study on the vibrational characteristics of ground".
N.N. Ambraseysm "Maximum intensity of ground movements caused by faulting".
V.V. Shteinberg, "Studies on the spectra of ground vibrations caused by nearby earthquakes".
C. Tamura, T. Mizukoski and T. Ono, "Characteristics of earthquake motion at the rocky ground".
I.M. Idriss, H. Bolton Seed and R. Dezfulian, "Influence of geometry and material properties on the seismic response of soil deposits".
S. Cherry, "Field investigation of the influence of site conditions on ground and structural response".
Kinji Akino, Takiharu Ota and Mirashi Yamara, "Seismic observations of rigid structure on various soils and its review".
D.E. Hudson, N.C. Nigam and M.D. Trifunac, "Analysis of strong motion accelerograph records".
Japanese National Railways. Dr Tatsua Mishiki, Kaichi Tamura and Masao Menogaki, "Control of train operation on the new Tokaido line on the occasion of earthquake" Apostol Poseski. "The intensity of ground motion of the Skopje 1963 Earthquake".
S.V. Modvedey, "Scale of seismic intensity".

Session B-2: Behaviour of Structural Elements.

D. Rea; R.W. Clough; J.G. Bouwkamp and U. Vogel, "Damping capacity of a model steel structure".
Hajime Umemura and Hiroyuki Aoyama, "Evaluation of inelastic seismic deflections of reinforced concrete frames based on the tests of members".
Vittelmo Bertero and Boris Bresler, "Seismic behaviour of reinforced concrete Frame structures".
M. Wakabayashi; T. Noneka and Ch. Matsui, "An experimental study on the horizontal restoring forces in steel frames under large vertical loads".
R. Tamura; M. Murakamia, Y. Osawa and N. Tanaka, "A vibration test of large model steel frame with precast concrete panel until failure".
S. V. Polyakov; H.V. Becheneva; Ju I. Kotov; and T.V. Potapova, "Bearing capacity of building materials under dynamic repeated loading".
A.C. Heidebrecht and W.K. Tso, "A research program on the earthquake resistance of shear wall buildings".
Minouri Yamada, "Low cycle fatigue fracture limits of

various kinds of structural members subjected to alternately repeated plastic bending under axial compression as an evaluation basis or design criteron for aseismic capacity".
Koji Mizuhata, "Low cycle fatigue under multi-axial stress concrete".
Toshio Shiga and Junji Ogawa, "The experimental study on the dynamic behaviour of reinforced concrete frames".
Lauren Carpenter and Le-Wu Lu, "Repeated and reversed load tests on full-scale steel frames"
G.N. Kartisivadze and L.N. Avalishvili, "Research on behaviour of reinforced concrete constructions under the effect of seismic load".
Seji Watanabe and Shozaburo Shimaguchi "On the aseismicity of Precast concrete curtain wall"
Thomas Paulay, "The coupling of reinforced concrete shear Walls".

Session A-3. Elastic Response of Structures.

Chairman - Joseph Penzien
John A. Blume, "Structural dynamics of cantilever-type buildings".
Y. Ohchi, "Response analysis of framed structures".
Simon Lamar and Celso Fortoul, "Brick masonry effect in vibrations of frames".
H. Sexton, R.J. Feibusch and E.J. Keith, "Dynamic analysis of tall buildings founded in deep fill materials."
R. Sheperd, "Dynamic elastic analysis in the design of typical New Zealand high-rise buildings".
Nathan M. Newmark, "Torsion in symmetrical buildings".
John A. Blume and Dilip Jhaveri, "Time-history response of buildings with unusual configurations".
Joseph Penzion, "Earthquake response of irregularly shaped buildings."
Paul C. Jennings, "Spectrum techniques for tall buildings".
Kazuhiko Takeyama, " A study on the earthquake response of space structures by digital computers".
R.W. Clough and A.J. Carr, "Dynamic earthquake behaviour of shell roofs."
Rudolph Szilard, "Estimating natural frequencies and nodes of arch dams with the theory of plates on elastic foundation".
S. S. Tozcan and S. Cherry, "Earthquake analysis of suspension bridges".

Session B-3: Large Buildings and Structural Details.

Chariman - K. Muts.
Sukenobu Tani, Joji Sakurai and Michio Iquchi, "An approximate method of static and dynamic analysis of corewall buildings".
Oscar de Buen, "Antiseismic design of multi-storey steel frames by plastic methods."
Carlos Jose Oto Larios and others, "Study of the behaviour of a hanging building under the effect of an earthquake".
Kiyoo Matsushita and Masanori Izumi, "Studies of mechanisms to decrease earthquake forces applied to buildings".
Y.P. Gupra and A.R. Chandrasekaran, "Absorber system for earthquake excitations"
Jack R. Benjamin, "Variability analysis of shear wall structures."
W. Gene Corley and Normal W. Hanson, "Design of beam column joints for seismic resistant reinforced concrete frames."
G. Cooper, "The use of steel to B S 968:1962 in the allwelded frame of a 19-storey building".
Sadaichi Torada and Akira Tsuruta, "Seismic moment resisting girder connecting to diagonally aligned columns".
Takeo Naka, Ben Kato, Makoto Watabe and Masami Makao, "Research on the behaviour of steel beam to column connections in the seismic-resistant structure".
Vitelmo V. Bertero, "Seismic behaviour of steel beam to column connected subassemblages."
E.P. Popov and R.B. Pinkney, "Reliability of steel beam to column connections under cyclic loading".

Session A-4: Inelastic Response of Structures.

Co-Chairmen - G. Housner and H. Kawassumi.
B.P. Guru and A.C. Heidbrecht, "Factors influencing the inelastic response of multi-storey frames subjected to strong motion earthquakes".
Robert D. Hanson and William F.B. Fan, "The effect of minimum cross bracing on the inelastic response of multi-storey buildings".
Paul Husid, "The effect of gravity on the collapse of yielding structures with earthquake excitation".
W.D. Iwan, "The distributed-element concept of hysteretic modelling and its application to transient problems".
Ben Kato and Hiroshi Akiyama, "The ultimate strength of the steel structures subjected earthquake".
Tadaki Koh, Hiromoto Takase and Tsunehisa Tsugawa, "Torsional problems in aseismic design of high-rise buildings."

T. Odaka, T. Susuki and K. Kinoshita, "Non-linear response analysis of multi-storey structures including rocking and swaying subjected to earthquake ground motions".
Akenori Shibata, Junichi Onose and Toshio Shiga, "Torsional response of buildings to strong earthquake motions".
R.A. Spencer, "The nonlinear response of a multi-storey pre-stressed concrete structure to earthquake excitation".
Ryo Tanabashi, Kiyoshi Kaneta, Tsuneyoshi Kakamura and Shunzo Ishida, "To the final state of rectangular frames".
A.S. Veletsos, "Maximum deformations of certain nonlinear systems".
W.R. Walpole and R. Shepherd, "The inelastic response of a steel frame".

Session B-4: Design of other structures

Chairman - M. Despeyroux
M.F. Barstein, "Dynamics of extended in-plan structures in strong earthquakes.
V.A. Bykhovsky, F.V. Bobrov and E.S. Medvedeva, "Some long-span construction in earthquake regions and choice of the type of structure on the basis of wave dynamic theory".
Y. Sonobe and T. Niskikawa, "Study on the earthquake proof design of elevated water tanks".
Muhail Ifrim and Christian Braru, "The effect of seismic action on the dynamic behaviour of elevated water tanks".
H. Sandi, "Water dam seismic interaction"
Bhaskar Nath and B. Tech. Ph.D., "Hydrodynamic pressures on arch dams during earthquakes".
Anil K. Chopra, E.L. Wilson and I. Farhoomand, "Earthquake analysis of reservoir dam systems".
A. Victoria Flores, L. Herrera and C. Lozano, "Hydrodynamic pressures generated by vertical earthquake component".
Nathan M. Newmark and William J. Hall, "Seismic design criteria fro nuclear reactor facilities".
Joseph A. Fischer and Williams J. Murphy, "Selection of design earthquakes for nuclear power plants".
Pavlyk V.S. "Study of earthquake resistance of boilers and recommendations for their design".
Ichiro Konishi and Yoshikazu Yamada, "Studies on the earthquake resistant design of suspension bridge tower and pier system".
Akio Sakurai and Tadashi Tadahashi, "Dynamic stress of underground pipe lines during earthquakes".

Session A-5: Soils and Soil Structures

Chairman - N.N. Ambraseys.
N.N. Ambraseys, "General report"
Eugenio Retamal and Edgar Kausel, "Vibratory compaction of the soil and tectonic subsidence during the 1960 Earthquake in Valdivia, Chile."
Robert V. Whitman and Pedro Ortigosa de Pablo, "Densification of sand by vertical vibration."
H. Botlon Seed and Kenneth L. Lee, "Pore-water pressures in earth slopes under seismic loading conditions".
C. Martin Duke, "Techniques for field measurements of shear wave velocity in soils".
Isao Minami, "On vibration characteristics of fill dams in earthquakes".
A.K. Chopra, M. Dibaj, R.W. Clough, J. Penzien and H.B. Seed. "Earthquake analysis of earth dams".
Jai Krishma, Shamashan Prakash and S.K. Thakka, "A study of earth dam models under shock loading".
Yoshimasa Kobayashi, Japanese National Railway, "Mechanism of earthquake damage to embankments of slopes".
Shamshar Prakash and B.M. Basavanna, "Earth pressure distribution behind retaining wall during earthquake".
Lavrov, Lycamzina and Medvedev, "Vibrations of earth dams during earthquakes".
Harano T. Watanabe H. "Seismic analysis of earth dams"
General Discussion.

Session B-5: Design Criteria and Research

Chairman- J. Ferry Borges.

Tashihiko Hidada, representing Joint Committee on Housing "Large size structures testing Laboratory and lateral loading test of a five-storeyed full size building structure".
Enzo Lauletta and Aldo Castoldi, "Earthquake simulation by shake table".
J.B. Bouwkamp, R.W. Clough, J. Penzien and D. Rea, "Design and research potential of two earthquake simulator facilities".
M.A. Sozen, S. Otani, P. Gulkan and N.N. Nielsen. "The University of Illinois Earthquake Simulator".
Nathan M. Newmark and Steven J. Fenves, "Seismic forces and overturning moments in buildings, towers and chimneys".
J. Ferry Borges and Arthurs Ravara, "Seismic design of traditional and pre-fabricated reinforced concrete buildings.
A. Arias, R. Husid and J. Monge, "Comments on the new

Chilean seismic code for buildings".
I.M. Goldenblat, N.Z. Nicolaenko, J.M. Eisenberg and A.M. Zharov "The problems of the reliability and optimality of the earthquake proof structures".
K. Matsushita, M. Izumi, Kuang-Jui Hsu and I. Sakamoto, "Factors to be considered in calculating the input earthquake force to buildings".
Martin Duka and Augusto Leon, "University of Chile-University of California Program on earthquake engineering".
General discussion on Research problems and design criteria.
Jack R. Benjamin, "A probabilistic model for seismic force design".
Cismigu Al, Titaru Em and Velkov M. "Criteria for earthquake resistance codes based on energy concept, draft design code".
N. Norby Nielsen and William H. Walker, "Earthquake engineering research in the United States."

Session A-6: Foundation and Soil Structure Interaction.

Chairman - William W. Moore.
S.B. Barnes, "Some special problesm in the design of deep foundations".
Hirishi Tajimi, "Dynamic Analysis of a structure embedded in an elastic stratum".
Edward L. Wilson, "A method of analysis for the evaluation of foundation structure interaction".
B.G. Korenev, V.A. Iljichjov and L.M. Reznikov, "Oscillations of tower-like structures with account of inertia and elasticity of solid medium".
J. Khanna, "Elastic soil-structure interaction".
Robert V. Whitman, "Equivalent lumped system for structure founded upon stratum of soil".
J. Kazuo Minami and Johi Sakurai, "Some effects of sub-structure and adjacent soil interaction of the seismic response of buildings".
William T. Wheeler, "Conventional foundations and earthquake problems".
Shamsher Prakash and B.M. Basavanna, "Effect of size and shape of foundation on elastic coefficients in a layered soil mass".
R. Minami, T. Kobori and Y. Inone, "On earthquake response of elasto-plastic structure considering ground characteristics".
Anil K. Chopra, and P.R. Perumalswami, "Dam-foundation interaction during earthquakes".
H. Kishida, K. Matsushita and I. Sakamoto, "Soil structure interaction of the elevated tower and of concrete footings.

K. Kubo, "Vibration test of a structure supported by pile foundation".

Session B-6: Small Buildings, Insurance Damage Repair

Chairman - Jai Krishna.
J. Monge, "Seismic behaviour and design of small buildings in Chile"
J. Krishna, "Strengthening of brick buildings in seismic zones.
C.M. Stachen, "Seismic classification system for old buildings in New Zealand.
F. Alberti, "Earthquake engineering as an aid to Insurability".
S. Arias, V. Arze and Jaime Bauza, "Repairs on power house and boilders support structure damaged by 1965 earthquake, Ventanas 115 MW Steam Electric Station (Chile)."
E. Arze, "Seismic failure and repair of an elevated water tank."

Session J-4: Special Papers

Chairman - Rodrigo Flores.
R. Flores, "An outline of earthquake protection criteria for a developing country".
K. Muto, "Earthquake resistant design of 36-storied Kasumigaseki building".
H.J. Degenkolt, "Limitations and uncertainties of present structural design methods for lateral force resistance".
C.W.O. Turner, "Earthquake: the universal menace".

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ATTENUATION OF MAXIMUM ACCELERATION

(after Cloud and Perez)

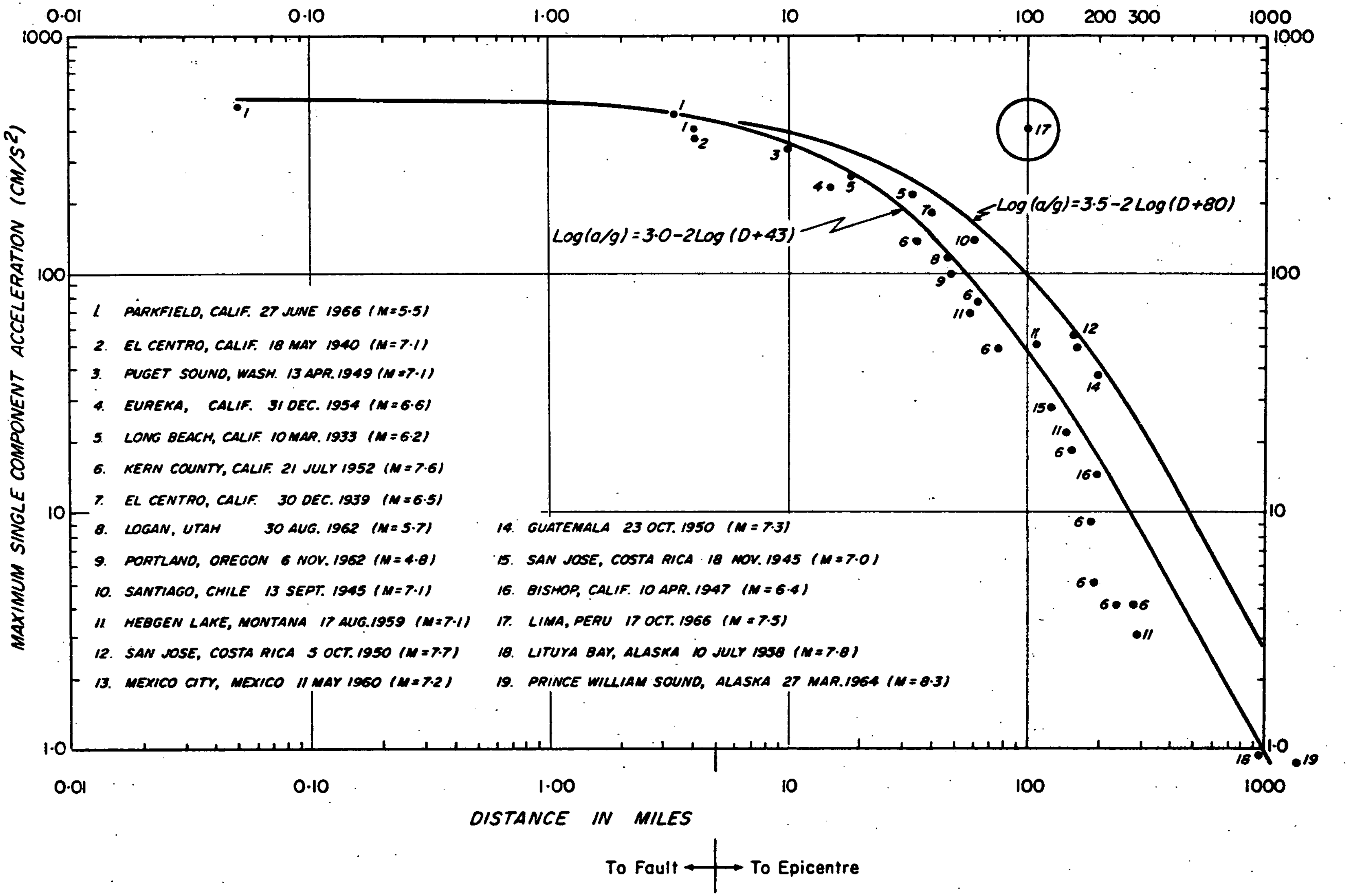

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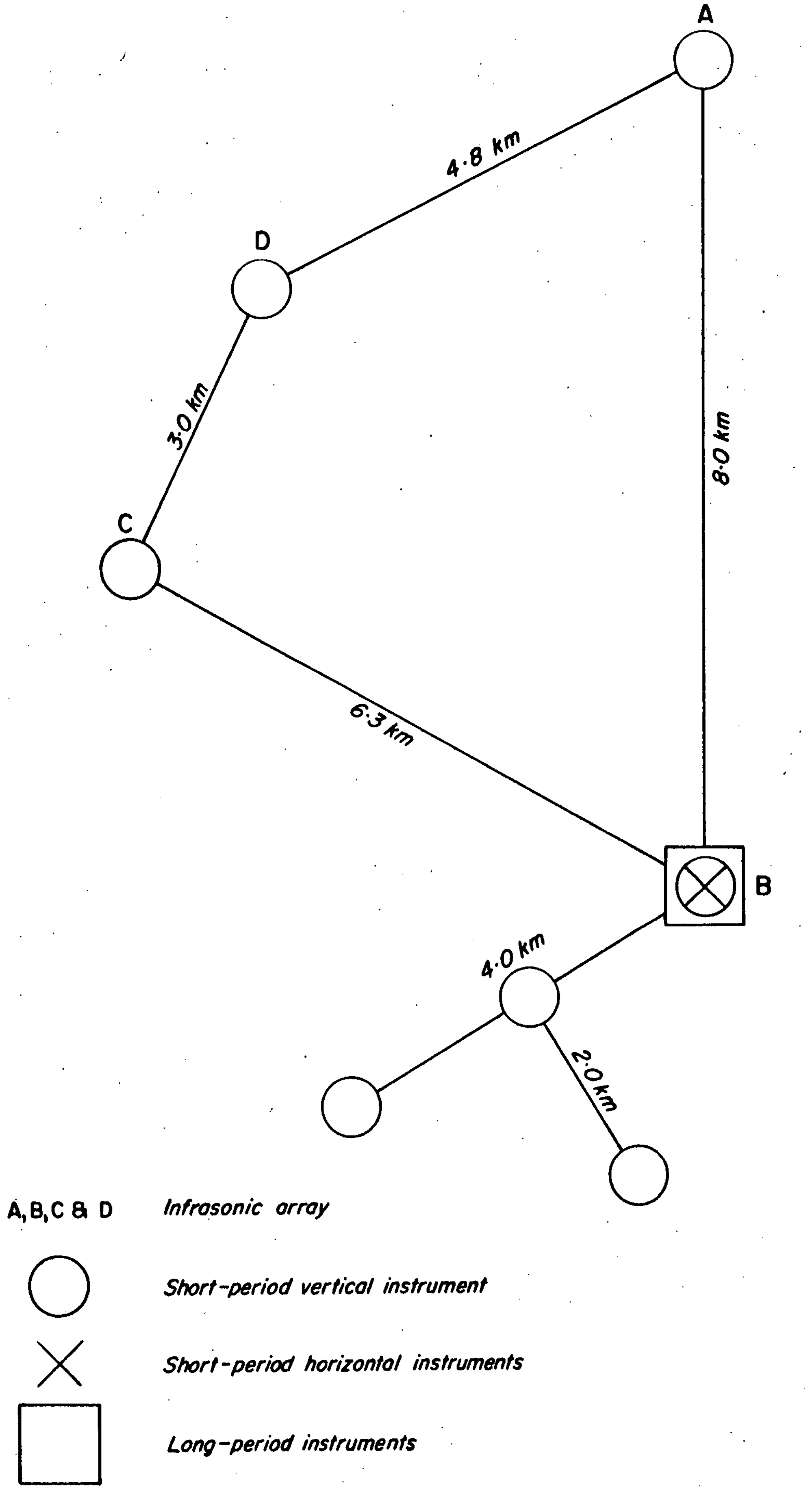
PLATE I

PLATE 2

APPROXIMATE DIMENSIONS OF PENAS ARRAYS



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LOCAL EARTHQUAKE DEPTH RESOLUTION

(after James et al.)