EARTHQUAKE ENGINEERING DEVELOPMENTS IN NEW ZEALAND, 1945-1955.

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Synopsis.

This paper reviews major earthquake distribution in New Zealand and geological aspects of seismic zoning in connection with building regulations. Strain energy released by earthquakes is graphed to show the continuing nature of engineering problems in the future. The research programme of the Dominion Physical Laboratory is described giving details of instruments made, the network of their locations, and accelerogram analysis for engineering purposes. An electrical analogue of a ten storey building which considerably shortens the time of analysis has been made at the Laboratory. Recent revisions of Standard Building By-Laws are discussed and suggestions made for the future.

Introduction.

During the past decade, New Zealand Engineers and Scientists have been giving much time and attention to the improvement of methods for the design of earthquake-resistant structures and works. It will be realised, of course, that certain precautions had been taken against earthquake damage since the earliest times and that following the Hawkes Bay earthquake of 1931, Standard Building Codes had been promulgated by the New Zealand Government(1). These regulations include provisions and regulations defining minimum requirements for earthquake-resistant design of buildings and they have been revised from time to time to include the best practices overseas. Most of these practices are of an empirical nature, are sometimes of limited application, and do not account for dynamic characteristics.

Stimulated by advances in scientific knowledge and observing at first hand the selective power of earthquakes for certain types and characteristics of structures, it was felt that a programme of research should be instituted. In 1946, following the delivery of a paper on the subject (2) at the annual conference, the N.Z. Institution of Engineers approached the N.Z. Government with a request for the initiation of a programme of research into the ground motions of the destructive phases of earthquakes which would provide information of engineering value. Accordingly, the Government of the day referred the matter to the Department of Scientific and Industrial Research and an Advisory Committee was set up consisting of Engineers, Architects and Seismologists whose function was to assist in formulating the proposed programme. The Dominion Physical Laboratory undertook the research and some of its activities are described later in this paper.

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Earthquake History.

The first white men to live in New Zealand experienced earthquakes. The earliest information is given by McNab who states that sealers in the Fiordland, Western Southland, experienced strong earthquakes in 1792 and Taylor records that sealers in 1826 and 1827 felt violent quakes over a long period. Organised European settlement of New Zealand began in 1840 and records have been kept since that date. Over the years there has been a gradual improvement in the extent and technique of recording earthquakes. Seismological observatories were established at Wellington and Christchurch and later other stations were set up.

A great deal of information has been recorded and issued from time to time. There have been strong earthquakes of deep focal origin which cause little damage on the crustal surface although they may be felt over a wide area. All damaging earthquakes in New Zealand are of shallow origin, occurring along fault lines in practically all cases. The epicentres of the sixteen most damaging shocks are shown in Fig. 1 together with the position of all the strong active fault lines. The numbers given refer to the order of occurrence of earthquakes. The time and magnitude, both on the Modified Mercalli Scale and the Instrumental Magnitude Scale, are given in the Table of Earthquakes shown on Fig. 2.

Geological Faulting.

It will be seen from Fig. 1 that the geological block structure of New Zealand is fairly well defined. There is a long rift structure running north-east and south-west. This rift structure contains a series of strongly active lines of faulting. It is well known that the locking and breaking of these fault lines is the cause of earthquakes. In a report from the N.Z. Geological Survey (1953) it is stated that recent studies have shown that most of the faults are strike-slip, except the White Creek fault which is compressional and those in the Wanganui-Bay of Plenty zone in which some are tensional. It has been estimated that the movement on the Wairau fault in the South Island averages $1\frac{1}{2}$ inches a year in a series of jumps at time intervals of perhaps 100 years. One movement will relieve stress and cause an elastic strain rebound. Each movement or adjustment can produce damaging quakes.

In Fig. 1 only strong active faults are shown. Isolated fault traces which are only a few miles in length are not classed as strong and are omitted. On almost all the strong active faults, movement has taken place repeatedly over a long period of time. One exception is the White Creek fault which was inactive for several thousands of years prior to the Buller earthquake in 1929, and the group through the thermal area where movement has not taken place repeatedly on the same fault, but rather in a zone.

Seismic Probability Zones for Building Codes.

In some countries it has been found useful to vary the building code requirements in accordance with a seismic probability map. There is a body of opinion among Engineers, particularly in the South Island, that this practice should be applied to New Zealand. The matter is still under consideration and it would be difficult to strike a boundary line beyond which code requirements could be relaxed. This is chiefly on account of the short historical period of New Zealand. As a commencement, one boundary line has been tentatively suggested by the N.Z. Geological Survey. This is a line drawn parallel to and 60 miles outside the line delimiting the zone of strong active faulting shown in Fig. 1. Zone 1 in this figure could perhaps be regarded as a zone of minor damage, and zone 2 in the central portion of the country would be classified as a zone of major damage. The fixing of the appropriate seismic factors to be used in design would also require further study.

General Deductions from Records of Seismicity.

In all problems confronting the Engineer it is usual for him to have some basic information as to the nature, size and frequency of the natural forces which could affect his works. In the case of engineering problems associated with floods, he is usually able to assemble his information in the form of graphs, and from a fairly full knowledge of the situation, to make his decisions or designs. In the case of earthquakes, only the very roughest of forecasts can be made and then only from historical information and not from purely physical data.

It is evident that the physical forces, stresses and strains causing earthquakes work on a very long geological time scale. It takes hundreds and sometimes thousands of years to develop movements as in the case of White Creek fault in the South Island. Then again, although we may know a good deal of the mechanism of earthquakes from a study of seismograms and fault traces, and can deduce the kind of stress acting on them, and the thickness, density and number of layers, we can never get the complete picture.

In order then to gain some idea of the future of earthquakes, the most reasonable and probably the only approach is from the study of the history and characteristics of past earthquakes. Some general trends can be seen in Figs. 2 and 3, but it is possible to deduce only very general conclusions.

Referring to Fig. 2, the relationship between latitude and time of occurrence of earthquakes has been plotted. This graph forms a useful aid to the study of the history of earthquakes in New Zealand. The strong tendency for quakes to alternate from north to south is of some interest and may suggest a clue as to what is occurring in the rift block structure. It should be noted that in order to complete the graph in the comparatively calm period between 1855 and 1888, shocks of magnitude $6\frac{1}{4}$ and $6\frac{1}{2}$ have been included in the plotting. The sixteen major earthquakes [3] are of instrumental magnitude 7 or greater. When the graph is read in conjunction with Fig. 1 the significant grouping of the following should be noted as being associated with activity on the same fault line; earthquakes numbered 4 and 5, 6 and 7, 8 and 9, 11 and 12, and finally 13, 14, 15 and 16.

Characteristics of Rate of Strain Release.

The method of calculation used in deriving the data for Fig. 3 is due to Benioff. The calculations and original plot of the graph were made by Mr. G. A. Eiby of the Seismological Observatory at Wellington. Although this graph is not identical with the original, the general characteristics of the curve may be taken as substantially correct. Points worthy of particular notice are the calm period between 1855 and 1888 and the gradual increase in the rate of strain release culminating in 5 major earthquakes in 5 years from the period 1929 to 1934. There has been only one major earthquake since 1934, viz. No.16 at Masterton in 1942.

It is impossible to make any useful deductions from Fig. 3; a calm period or cycle may be starting as in 1863 or it may not, but one fact is that the graph lends force to the reminder in a recent lateral force code [4] that "in any event, there is no justification in the historical record for complacency or indifference to the design of earthquake forces".

Since the situation has many possibilities, it is important that we proceed with research and that we provide adequate protection in the design of all engineering works and buildings.

Strong Motion Research Programme.

The events leading up to the Dominion Physical Laboratory undertaking the proposed research have already been given.

It was at first intended to purchase six accelerometers of the Wenner type and as a commencement one was bought and installed at the Seismological Observatory in Wellington. It was then found that the high cost of the Wenner type made it necessary to design and build lower cost accelerometers on an electronic principle. At the Dominion Physical Laboratory there were physicists and technicians who were well trained in electronic principles and equipment was freely available. It was estimated that the cost could be reduced by half in adopting this type. The most urgent need in the proposed programme of strong motion research was the installation of some accelerometers at well selected sites. It was not possible to obtain staff at once and so, after some delay, six instruments known as the "Strong-motion Seismograph Type EB" were designed and made.

Electronic Seismograph.

As these instruments are fully described in a recent paper [5] by Taylor and Harrison, it is unnecessary to give more than a brief description. There are two main units, the cabinet and the ground unit. The cabinet contains the recorder, battery charger, amplifier, high tension and low tension batteries. The ground unit contains the two accelerometers (N-S and E-W) together with the trigger device.

As with the Wenner type, the instrument is set to be triggered off by the arrival of P waves of an earthquake. The trigger consists of a pendulum which, when disturbed, closes a circuit and a relay operates the recorder. The two accelerometers are of orthodox design and have a natural period of .08 sec. The recorder is a four-channel high speed pen recorder available commercially and specially designed for recording stress and vibration phenomena. The pickup of three coils and a moveable core operates on the shaft of the accelerometer mass, and the paper speed of the recorder is 2.5 cm/sec. The ground unit is mounted on a heavy steel plate which is attached to a concrete slab buried in the ground.

Wenner Seismograph.

The Wenner type consists of three accelerometers to record the three components of ground motion, a starter unit and a time-marking clock, a lamp and a recording drum on which photographic paper is fastened. All equipment is kept inside a light-tight box and optical magnification is employed in recording the earthquake.

The Wenner accelerometer forms a useful part of the instrumental set-up in New Zealand and has already recorded earthquakes of moderate and low intensity.

Maximum Force Meters.

It will be realised that for the complete instrumental coverage of New Zealand it would be necessary to have a great number of instruments. In order to obtain adequate coverage economically, a number of maximum force meters which will record the maximum acceleration have been installed. These were also constructed at the Dominion Physical Laboratory and fall into two types.

Smoked Glass Type.

The first is the smoked glass type of maximum force meter which is illustrated in Fig. 4. It consists of an inverted pendulum rigidly fixed at the base and having a spring steel shaft which carries a metal mass. An arm extending the system vertically through a magnetic damping field is cranked around the smoked glass plate on which it records with a spring loaded stylus. The stand carrying the instrument is screwed to a heavy base.

Toppling Tombstone Type.

The second type is an array of six shafts and masses each of which can be disturbed only by a nominated proportion of gravity acting in a horizontal plane. If the acceleration is equal to or greater than that noted on each system in Fig. 5 the shaft will deflect sufficiently at the top to cause the mill-headed pin at the top to drop beside the flat end pin support. It thus records the maximum value of acceleration within the prescribed limits of the instrument. It is felt that these meters will have considerable value to the Engineer in fixing the susceptibility of various areas and classes of ground to the destructive phases of earthquakes. The term "toppling tombstones" is a reference to the similar type of information sometimes obtainable at cemeteries after a bad earthquake. The location of maximum force meters and accelerometers totalling 42 in New Zealand is shown on Fig. 6. The average spacing of these 42 various instruments forms a grid system the sides of which are about 40 miles, so that an instrument would not be more than 20 miles away from any possible earthquake.

Analysis of Earthquake Records.

The main object of the programme of research is to obtain information which will be of value to the Engineer in the design of earthquake resistant structures. The proper interpretation and analysis of records is therefore one of the main tasks of the Dominion Physical Laboratory and thus must be done in close liaison with Engineers in practice so that the practical side of proposed methods is given full consideration. The earthquakes so far experienced since the installing of the Wenner and other instruments have been of light intensity.

Torsion Pendulum Analyser.

In Fig. 7 an illustration is given of an instrument constructed at the Laboratory which has been used to analyse several New Zealand quakes. This instrument has been built here from information obtained from the United States. Itis called a Torsion Pendulum Analyser and consists of five main parts - the rotating drum to which the accelerogram is fastened, the stylus and linkage which translates transverse movement into torsion, the torsion head and torsion wire, an adjustable horizontal pendulum and a recording device for maximum swing of the pendulum. It is readily seen that when the record is fixed to the drum and rotated at one-tenth the speed of the original record by a small motor (not shown), an operator is able to trace the transverse component of the record as it passes slowly under the stylus. He thus imparts an angular rotation to the torsion head which is proportional to the acceleration changes.

Any special characteristics of the record such as resonance or near-resonance is reflected in the response or swing of the horizontal pointer. Teledeltos paper placed on top of the curved recorder plate is marked by means of an electric spark from a current induced in it.

Having analysed a series of different pendulum periods and obtained the maximum swing, the results are plotted as a graph called the earthquake spectrum. An example of this is given in Fig. 8 (after Taylor) (6). It is from graphs such as these that a standard spectrum for use in design is derived.

Analysis by Admiralty Wave Analyser (7)

The Admiralty Analyser has also been employed in the analysis of earthquake records and is regarded as a useful check to detect high accelerations which may have been missed.

The Electrical Analogue of a Ten Storey Building.

An electrical analogue of a ten storey building which has been in the process of design and construction for some time was completed during 1955. Only a brief description is given here as it is dealt with fully elsewhere in a paper by the persons who designed and built it (8). This ingenuous equipment enables an operator to rapidly set up three properties: (1) a series of electrical inductances marked L in Fig. 9 to represent exactly the mass characteristics of each storey of any building, (2) a series of condensers N to simulate the lateral shear rigidity of each successive wall and column system supporting each floor, and (3) a series of resistances "M" to represent numerically the damping characteristics of each storey.

Having set up this electrical analogue of a building and arranged each storey in the correct order, the whole system is then subjected to electrical impulses which reproduce the dynamic characteristics of an accelerograph record of an actual earthquake. This is done as follows: the area of an enlarged trace of the accelerogram is half filled in with black ink so that one side of the trace is black and the other white. The trace is then affixed to the rim of the wheel A and occupies only a short sector, the rest of the rim being half white and half black. A lamp "B" throws a thin strip of light "C" across the black and white trace. As the wheel turns the greater reflecting power of the white makes the strip of light appear to be varying in length as it transversely scans the trace. The varying amount of light is reflected on to the two photo cells at D. The resulting electric impulses from the photo cells are conducted to the amplifier and power pack "E" and "F" and thence fed into the electric analogue at the first storey "G", thus subjecting the building to the equivalent accelerations of an earthquake.

These accelerations act upon the mass components (inductances marked "L") to produce the equivalent of lateral forces acting at each floor level. By turning the selector knob "H" the shear rigidity response of any particular storey is displayed on the oscilloscope screen. The response of the shear rigidity components of the analogue (the condensers marked "N") modified by the damping components (the resistances marked "M") is displayed on the screen momentarily as a vertical line. At its maximum elongation of line, a photograph is automatically taken by the movie camera. The rate of exposure of photographs is electrically synchronized with the rate of repetitions of the short sector of the earthquake trace. By allowing the wheel carrying the trace to run down, the repetitions occur at regularly decreasing speeds. A decrease in speed has the same relative effect as an increase in the natural period of vibration of the building. Thus each successive change in length of vertical line represents a plot of the ordinate of the earthquake spectrum. The complete spectrum is generated on the movie film. One film is made for each storey.

It is reported that the complete process described above can be carried out for each storey of a building in about three quarters of an hour; consequently it is felt that the process constitutes a distinct forward step in the structural evaluation of earthquake phenomena.

Towards the end of 1955, assistance was given in the work of installing both strain gauges and seismographs in a new 10 storey block of flats in Wellington.

Measurements of Building Vibrations.

This work has not proceeded very far up to the present.

A horizontal vibration meter has been developed and described by Taylor(6), who has also conducted tests on storied concrete buildings for the purpose of determining the natural periods of vibration. No organised programme has yet been started.

Building a Ground Vibrator.

For the complete analysis of a building a vibrator is necessary. A machine designed for a maximum thrust of 3,400 lb. at frequencies up to 15 cycles has been built by the Laboratory in preparation for building vibration work.

N.Z. Standard Code of Building By-Laws.

Seismic Coefficients.

Recent revisions of the N.Z. Standard Code have made small amendments to various clauses with the result that the requirements of design in connection with strength against seismic forces can be expressed broadly as follows: The value of the seismic coefficient for buildings designed in connection with public services such as hospitals, public halls, schools, churches, theatres, etc., shall not be less than 0.10 for uniform loading continuously applied as a horizontal force in any direction. As an alternative, the seismic coefficient may be taken as having a value of zero at the base of the building and rising to a value of 0.12 at the top of the building. The coefficient at any floor level or other required point shall be obtained by linear interpolation.

For parapet walls and exterior ornamentations the coefficient is 0.5, and for towers and tanks (including contents) chimneys, smokestacks, and penthouses when connected to or when part of a building, the coefficient is 0.2.

For towers, tanks (including contents), chimneys and smokestacks not directly tied to the building the coefficient is 0.1.

For electric power stations and distribution substations the seismic coefficient is one-sixth, and for buildings other than those specified above, the coefficient is taken as 0.08 with the permissible alternative of using the triangular loading identical with that specified for public buildings above.

Seismic Loading of Building.

The seismic weight of buildings to be used in the calculation of horizontal seismic forces shall include all dead load plus 2/3rds of the design live load for storage and warehouse floors, and plus 1/3rd of the design live load for all other floors including roofs.

The continuously applied horizontal force shall be the weight of the building as set out above, multiplied by the seismic coefficient as given above.

P robable Developments in the Future.

It will be noticed that the present Standard Code of Building By-Laws has many points in common with the Lateral Force Code of the American Society of Civil Engineers [4]. It is felt that in future there will be a tendency to adopt the portion of the latter code dealing with the application of the dynamic approach to earthquake forces, but until more research work is done in the testing of the vibration characteristics of buildings in this country, New Zealand Engineers will probably be reluctant to develop the method too far.

In connection with existing buildings which were built before the introduction of the Code, it seems that some scheme should be developed whereby adequate strengthening is enforced. It seems probable that many of these buildings are the result of the "calm period" mentioned in connection with Fig. 3 and perhaps particularly in the 1920's. They have, however, stood safely for a great number of years, being built in the popular material of construction-brick and masonry. There is little doubt that they now constitute a serious hazard. The problem is of sufficient importance to justify early research into acceptable tests for soundness and resistance to horizontal force and the enforcement of strengthening measures.

Conclusion.

In reviewing New Zealand's susceptibility to earthquakes, it is found that, while there is little evidence that the scale of seismic activity is increasing or decreasing, there is ample indication that earthquakes will continue to be part of our environment. It is therefore important that adequate provision should be made to minimise their damaging effects on structures. The geological formation of the country is suggested as a reasonable basis for seismic zoning if such is required. The Dominion Physical Laboratory has made some valuable progress in the last few years in providing seismological services of an engineering nature. The full value of the work of research on ground motion will not be properly appreciated at present, but will form the basis of engineering development in future generations.

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Figure Captions.

Fig. 1 Major Earthquakes and Fault Lines of New Zealand.

Fig. 2 Relationship between Latitude and Time of Earthquake.

Fig. 3 Graph of Strain Release Increments against Time.

Fig. 4 Maximum Force Meter - Smoked Glass Type.

Fig. 5 Maximum Force Meter - Toppling Tombstone Type.

Fig. 6 Map of Location of Maximum Force Meters and Accelerometers.

Fig. 7 Torsion Pendulum Analyser.

Fig. 8 Result of Accelerogram Analysis of Torsion Pendulum.

Fig. 9 An Electrical Analogue of a 10 Storey Building.

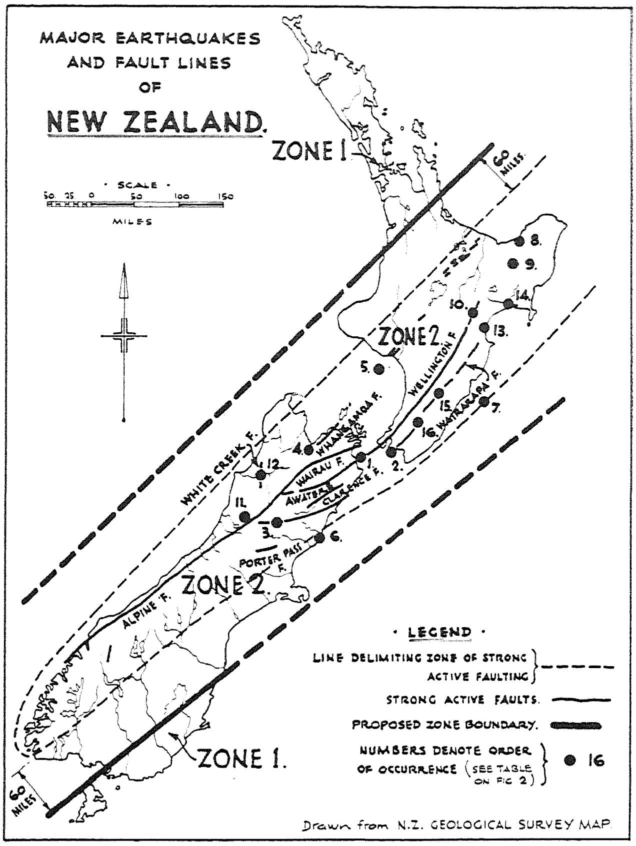
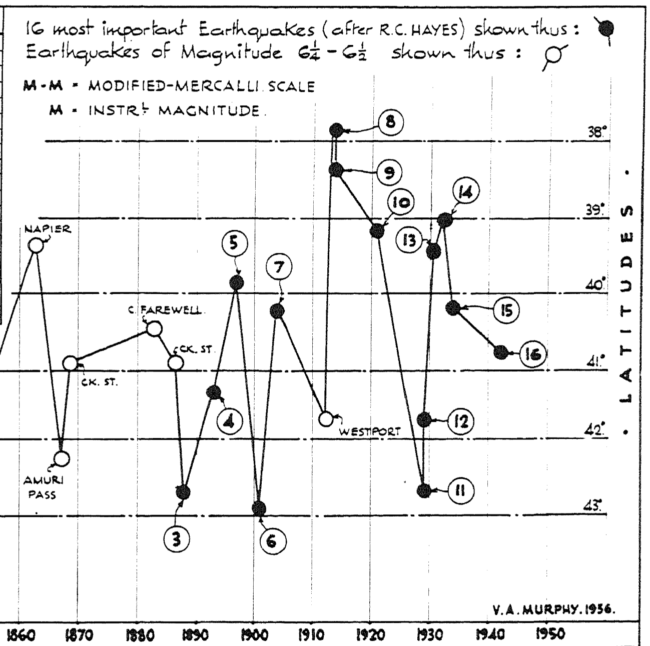


Fig. 1



ORDER OF TIME.		EPICENTRAL REGION.	M-M (SCALE)	M
1	1848.	N.E. MARLBOROUGH.	10.	7½
2	1855.	S.W. WAIRARAPA	11+	8ca.
3	1888.	N. CANTERBURY	8½.	7.
4	1893.	NELSON.	7½	6½-7.
5	1897.	WANGANUI BIGHT.	8½.	7.
6	1901.	CHEVIOT.	9.	7.
7	1904.	OFF CAPE TURNAGAIN.	9ca.	7½
8	1914.	E. BAY OF PLENTY.	9ca.	7-7½
9	1914.	N.E. NORTH ISLAND.	7ca.	6½-7
10	1921.	HAWKE'S BAY.	7½	7
11	1929.	ARTHUR'S PASS.	9ca.	7½
12	1929.	BULLER.	11	7¼
13	1931.	HAWKE'S BAY.	11	7¾
14	1932.	WAIROA.	8+	7¼
15	1934.	PAHIATUA.	8½	7½
16	1942.	WAIRARAPA.	8	7ca.

•TABLE OF EARTHQUAKES•
(AFTER HAYES 1953.)

Fig. 2

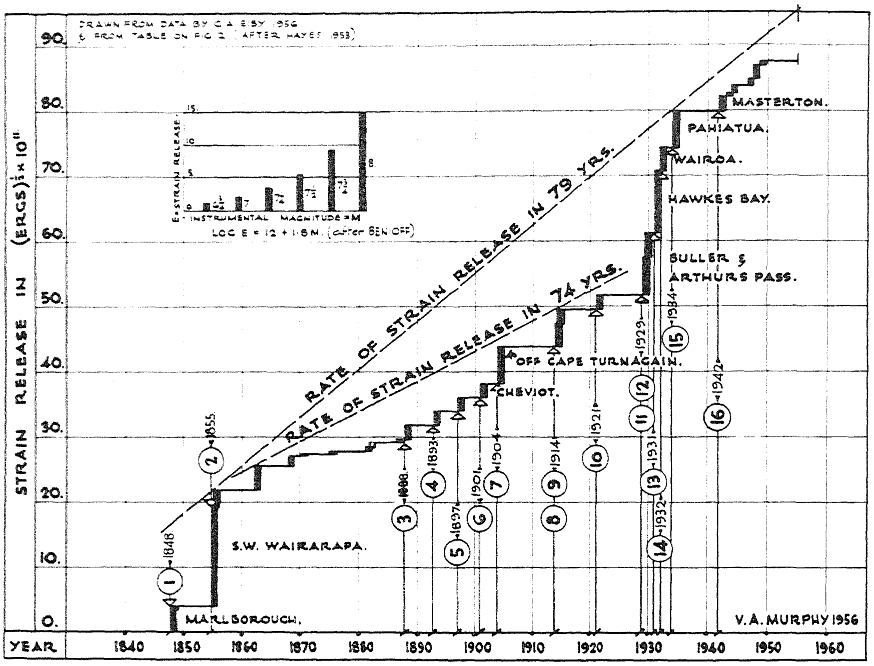

STRAIN RELEASE IN (ERGS)½ × 10¹¹
RATE OF STRAIN RELEASE IN 79 YRS.
RATE OF STRAIN RELEASE IN 74 YRS.
MARLBOROUGH.
S.W. WAIRARAPA.
CHEVIOT.
OFF CAPE TURNAGAIN.
BULLER & ARTHURS PASS.
HAWKES BAY.
WAIROA.
PAHIATUA.
MASTERTON.
INSTRUMENTAL MAGNITUDE = M
V.A. MURPHY 1956
YEAR

Fig. 3

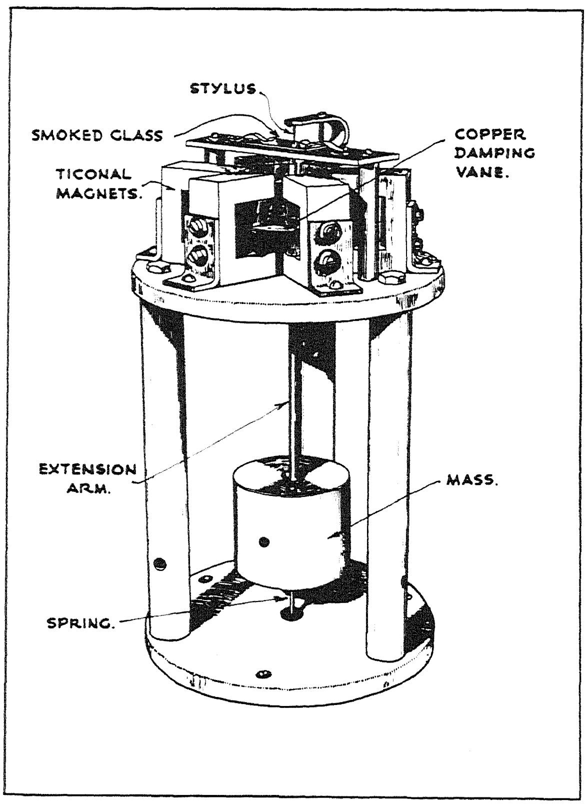
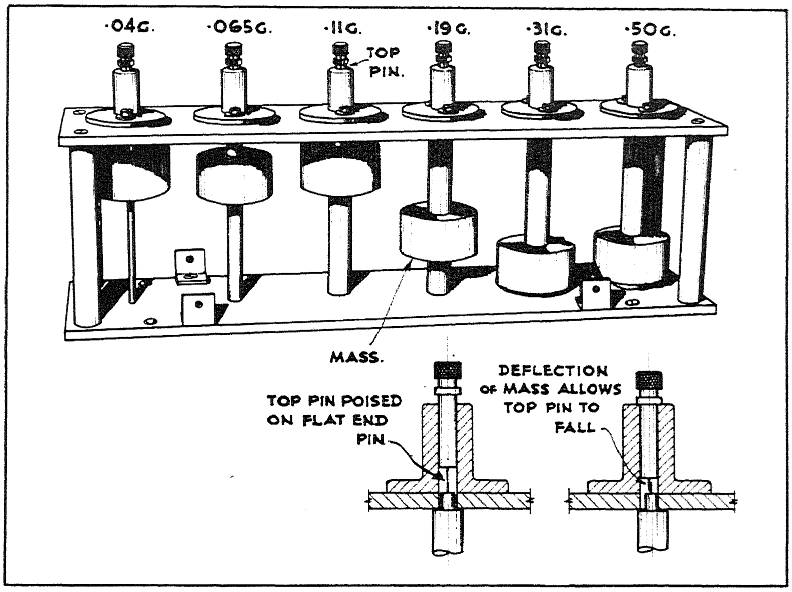
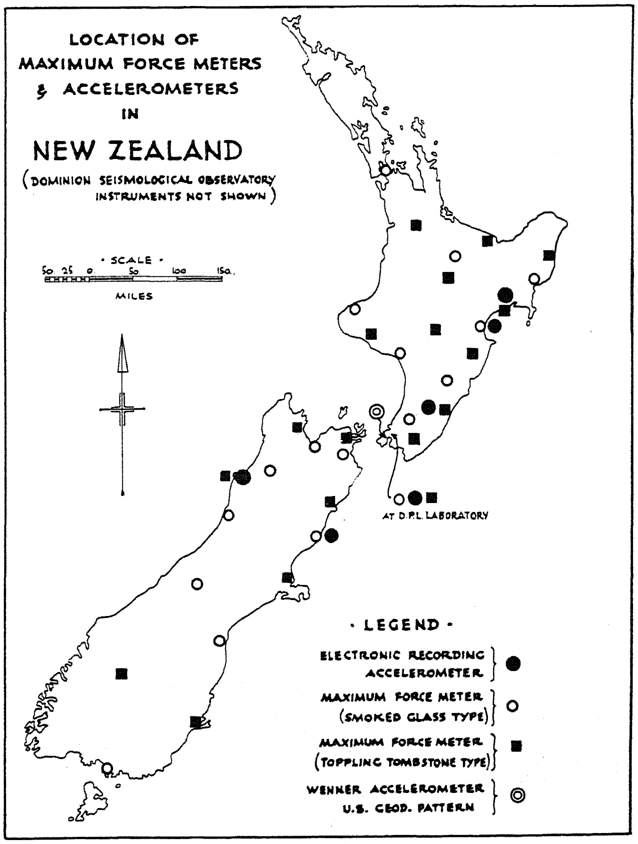

STYLUS.
SMOKED GLASS
COPPER DAMPING VANE.
TICONAL MAGNETS.
EXTENSION ARM.
MASS.
SPRING.

Fig. 4



·04G.
·065G.
·11G.
TOP PIN.
·19G.
·31G.
·50G.
MASS.
TOP PIN POISED ON FLAT END PIN
DEFLECTION OF MASS ALLOWS TOP PIN TO FALL

Fig. 5



LOCATION OF MAXIMUM FORCE METERS & ACCELEROMETERS IN
NEW ZEALAND
(DOMINION SEISMOLOGICAL OBSERVATORY INSTRUMENTS NOT SHOWN)
· SCALE ·
50 25 0 50 100 150.
MILES
AT D.P.L. LABORATORY
· LEGEND ·
ELECTRONIC RECORDING ACCELEROMETER
MAXIMUM FORCE METER (SMOKED GLASS TYPE)
MAXIMUM FORCE METER (TOPPLING TOMBSTONE TYPE)
WENNER ACCELEROMETER U.S. GEOD. PATTERN

Fig. 6

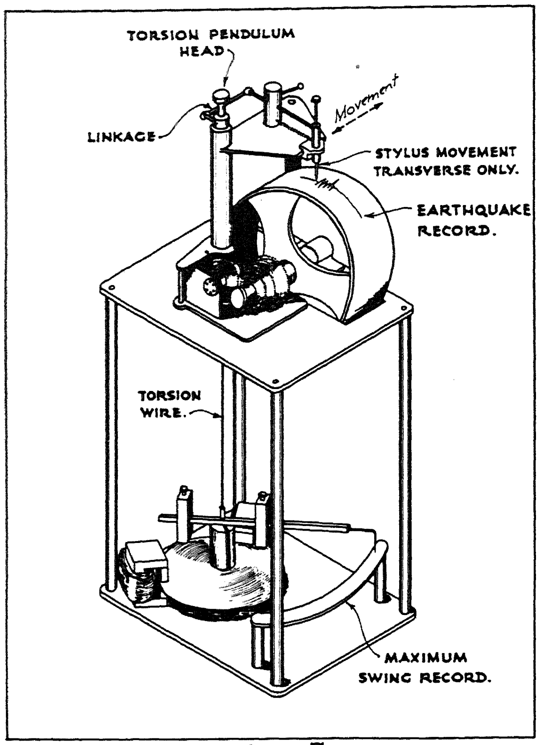


Fig. 7

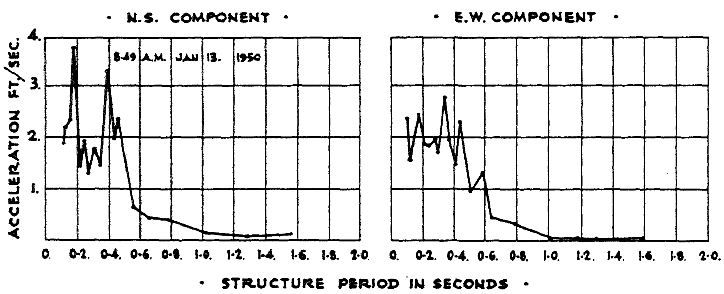


Fig. 8

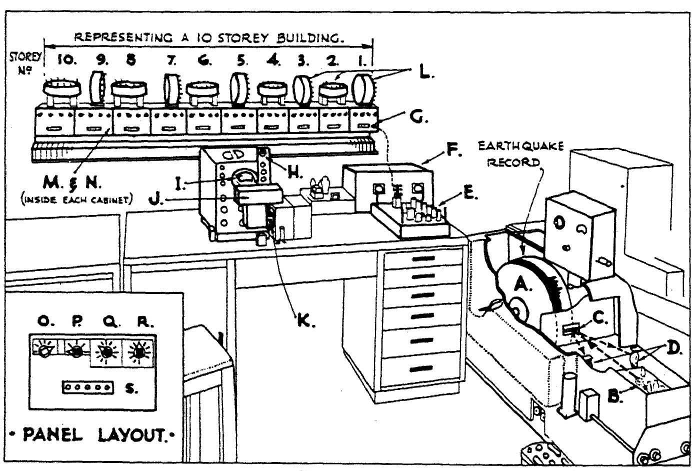


Fig. 9