NEW STRONG-MOTION ACCELEROGRAPHS

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Abstract

Two new accelerographs are described. The first is a three-component instrument which gives a good performance with reliability at a low cost. It achieves this by using a simple approach with some novel features. The second accelerograph is a very simple instrument which traces the end-point of the horizontal acceleration vector. This has been constructed at a very low cost.

1. Introduction

A keen demand exists for strong-motion accelerographs of high performance and low cost. They should be installed extensively throughout seismic regions, to gather the primary data required for the efficient design of earthquake resistant structures. A three-component accelerograph suitable for this work has been developed at the Physics and Engineering Laboratory. It is simple and should be inherently reliable, partly as a result of some novel features.

A further instrument of very low cost has also been developed, which provides limited but useful data on horizontal accelerations. It traces the end-point of the acceleration vector as a "clover-leaf" pattern; no timebase is available. This instrument is so inexpensive that it may be installed in large numbers on the ground and also throughout buildings.

To obtain data on earthquake accelerations most efficiently for a given expenditure, a large number of inexpensive non-timebase accelerographs should be operated in conjunction with a limited number of three-component timebase accelerographs. We discuss the pattern of locations at which the simple two-component accelerographs are being installed throughout New Zealand.

2. Three-Component Accelerograph M.O.1

2.1 General Description

The three-component accelerograph uses a mechanical-optical system which records the accelerations on 35 millimeter photographic film. The basic components of the accelerograph are shown in Fig (1). A single lamp and pinhole illuminate three "pendulums", which are used to sense the components of acceleration. Mirrors mounted on the pendulums focus the pinhole onto the recording film. Each light spot traces out an enlarged record of an acceleration component on the moving film.

The instrument is started by a P-wave trigger, it runs for 45 seconds, and can make 9 separate runs before requiring attention.
Cassettes permit daylight loading and unloading of the film.

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2.2 Accelerometer Pendulums

The sensing elements of the accelerograph are in the form of two inverted pendulums and one horizontal pendulum. In each case the small pendulum mass is supported on four fine beryllium-copper wires, which are crossed in pairs giving a "camp-stool" configuration, Fig (1) inset 2. The elasticity of these four wires gives the pendulum an undamped natural frequency of about 30 c/sec. The wires constrain the pendulum to rotate about a fixed horizontal axis. The pendulum moves with negligible hysteresis and avoids the potential defects associated with pivot-point supports. The crossed-wire supports are assembled simply by soldering the wires into locating slots in the fixed base block and in the moving pendulum mass. Part of the pendulum mass is a glass cube which has a spherical mirror formed on one face. This is fixed into place with Araldite epoxy resin cement.

Damping is provided by silicone oil. The pendulum mass carries a paddle which moves above the base but close to it, in a pool of oil. The oil viscosity is chosen to give the pendulum a damping which is approximately 60% of critical. The whole pendulum assembly is hermetically sealed.

Each of the two vertical pendulums, which sense the horizontal components of acceleration, has its mirror mounted vertically but at 45 degrees to its (horizontal) axis of rotation. Two of these pendulums are mounted side-by-side, with their mirrors both facing along the axis of the accelerometer but with their axes of rotation at right angles.

The vertical acceleration is sensed by a third pendulum mounted with its central axis horizontal and its axis of rotation also horizontal. This third pendulum has a mirror facing along its central axis and has a modified damping configuration.

A fixed mirror provides a reference line on the recording film. Adjustments are provided to ensure that the light spots from all the mirrors lie on one line across the film.

2.3 Film Transport

The leading end of the recording film is attached firmly to a 3-inch diameter take-up drum, and the trailing end is attached to the centre of a cassette spool. During a recording run the outermost turn of film on the rotating drum moves past the signal light spots.

As the film is wound up on the drum the optical path from the pendulum mirrors is shortened; but this change is accommodated by the depth of focus of the optical system. A small change occurs in the time scale, as the film builds up on the drum, but this can be removed conveniently by using a similar transport while reading off the record.

Unperforated film is used as this can be drawn smoothly through the light-trap of the cassette; also it has a greater width available for recording.

The take-up drum is driven at 4 r.p.m. by a precision D.C. motor(with gear box). This commercially-available combination was developed as an integrator for analogue computors, and provides a film drive which is sufficiently accurate to remove the need for timing marks.

The record is recovered by winding it back onto the cassette spool. A slipping clutch permits the drum to turn on its drive shaft. This clutch also protects the gear box from overload.

A simple device, Fig (1) inset 1, ensures that the film can be readily attached and detached from the drum or spool. The end of the film is folded back and the fold pushed into a slot in the spool until the end catches on a leaf spring. The film is then firmly held, but can be detached by pushing it further in until the folded part springs open on reaching the far end of the slot.

2.4 Lamp and Pinhole

The lamp has a compact filament which is placed close to a pinhole of 0.002 inch diameter. The light from the pinhole is reflected by a plane mirror onto the three pendulum mirrors and the fixed reference mirror. These mirrors focus the light onto the recording film, giving effective light spot diameters of about 0.003 inch. The focus of these light spots on the film is adjusted by moving the lamp and pinhole assembly along the optical axis.

2.5 Trigger Unit

The equipment is switched on by an electromagnetic P-wave trigger. This consists of a 10 000 turn coil which moves vertically on a set of springs, in the field of a permanent magnet. Large clearances are provided and the unit is sealed to exclude foreign material from the air gap. This moving coil avoids the potential troubles of contact systems. When the coil velocity generates a sufficient voltage, a transistor switches on the lamp, the motor and a timing circuit. After 45 seconds the timing circuit switches off everything except the trigger transistor (which draws a very small current). This cycle is repeated if a further trigger pulse now occurs; sufficient film is provided for 9 separate runs.

2.6 Table of Characteristics of M.O.1

The main features of the 3-component accelerograph are as follows:

Accelerometers	2 horizontal and 1 vertical
Displacement meters	none
Natural period	0.03 sec.
Sensitivity	12.5 mm per one g
Recording range	0.01g to 1g
Traces and trace width	4 total; 1 fixed, 3 variable; width 0.075 mm.

2.6 Table of Characteristics of M.O.1. Cont'd/..

Time marking	not required, precision drive.
Recording medium	35 mm film, 25 ft.
Speed and duration	1.5 cm/sec; 45 sec; starts 9 times.
Recording drive	precision D.C. electric motor
Starter	
Component	vertical
Type	pendulum; emf (no contact)
Period	0.2 sec.
Sensitivity	velocity sensitive; approx 0.01 g acceleration
Damping	low
Starting time	approx. 0.1 sec
Power supply	12 volts D.C., internal dry cells
Size	12 x 12 x 24 inches
Weight	35 lb.

3. Very Low Cost "Peak Reading" Accelerograph S.P.2

3.1 Function

The accelerograph, Fig (2), is an inverted pendulum with an undamped natural period of about 0.05 seconds and a damping factor of about 60% of critical, the damping being provided by silicone oil. The relative displacement of the pendulum weight, with respect to the base, is a measure of the amplitude and direction of the horizontal acceleration of the instrument.

The movement of the pendulum weight is amplified by a light extension arm into which is plugged a smoked glass disc on its sleeve. A fine line is inscribed on the smoked surface of the moving disc by a sapphire stylus thus giving the acceleration record. The stylus is supported from the frame of the instrument by two pairs of beryllium-copper wires which provide rigid support against horizontal forces while allowing free vertical movement.

The sapphire stylus inscribes a sharp-edged line with a width of about 0.0005 inch; the glass disc moves about 90 thousandths of an inch for an acceleration of one "g". The record is reproduced photographically with a magnification of 100, giving a scale of 9 inches for one "g". The nominal resolution is 0.01 "g" on large acceleration pulses.

3.2 Operation

Operation is particularly simple as the following description shows.

The glass disc is prepared for recording by passing it through the flame of a wax match or taper. This gives a thin layer of smoke which is fixed with Shellite cleaning fluid (Shell X-55). The instrument cap and attached stylus are now slid upwards from the retaining lugs. The smoked glass disc (on its supporting sleeve) is plugged into place on the top of the extension arm. Before the cap is replaced, a small magnet is placed on top of it; this keeps the stylus holder in a raised position against the transparent top of the cap - the cap can then be replaced without marking the smoked disc. The last step is to remove the magnet and thereby lower the stylus to the recording position.

After an earthquake the glass disc containing a record of the ground acceleration is removed. The first step is to raise the stylus with a magnet so that the instrument cap may be removed without adding false marks to the record. A freshly prepared disc replaces the used one, which is returned to the laboratory and photographed at a magnification of 100.

3.3 Simplicity of Construction

The parts of the instrument are cut from stock sheet, tube and wire; the spring being cut from silver steel bar and hardened. Except for the spring diameter which influences the sensitivity, the dimensions of these components need not be controlled closely. The glass disc is a half inch diameter microscope cover slide. The sapphire stylus, with a tip radius of 0.0005 inch, is the type used in stereophonic record players. The stylus holder is supported on two pairs of beryllium-copper wires of 0.006 inch diameter. This arrangement gives rigid support against horizontal forces while allowing free vertical movement. (A writing pressure of about one gram is used.) Most of the assembly is by Araldite epoxy resin cement, but the spring is soldered into the base of the instrument, and the lugs which hold the cap are bolted in place.

3.4 Reliability

The setting-up procedure is very simple and virtually fool-proof. There are no sensitive or critical features which can lose their adjustment. No trigger is required. It is expected that the instrument will perform reliably even over long periods between inspection visits.

The instrument is protected from shock or damage by a locked steel cover box which is separately bolted to the concrete floor.

3.5 Testing and Calibration

The instrument was tested on a shaking table, with a sinusoidal movement of various frequencies. It was also tested on an impact table which gives an acceleration impulse of controlled size and duration.

The final calibration was by static tests. The instrument was attached to a turntable with its axis tilted from the vertical direction. Under slow rotation the instrument drew a circle. The test was repeated for various angles of tilt, giving a series of concentric circles. These gave the sensitivity and linearity of the instrument in any horizontal direction.

3.6 Distribution throughout New Zealand

The seventy-odd sites selected for the installation of the peak-reading accelerographs are shown in Fig (3). They have been distributed throughout New Zealand as widely as possible. There is some bias in favour of areas which have a large number of recorded earthquakes, and in favour of areas containing major structural works.

In addition, a dense pattern of 25 peak-reading accelerographs is proposed for the Wellington-Hutt area. These should throw light on micro-zoning problems. (They will be supplemented by four or five of the three-component accelerographs).

While the present network of peak-reading accelerographs is being installed to record ground accelerations, the instruments can of course equally well measure the peak earthquake-generated accelerations of points in a building. Further instruments will be constructed for this purpose.

4. Discussion

The three-component accelerograph has performed well under laboratory tests. None of these instruments have yet been installed in the field, but the laboratory tests lead us to expect reliable operation with servicing visits up to one year apart. The cost of the instrument is substantially lower than that of existing instruments. Novel features which contribute to the performance and expected reliability are the crossed-wire pendulum support, the simple film transport and the absence of a time-marking mechanism. The method of film attachment has proved to be very convenient. It is evident that further improvements in performance and reduction of cost are possible in an instrument constructed along these lines.

The "peak reading" accelerograph is very simple and inexpensive. It seems unlikely that further development will give marked improvements. However, it may be possible to obtain an approximate time-base from earthquake-induced high frequency vibrations (say 80-100 c/sec) of the extension arm.

The stylus holder is very inexpensive indeed and performs exceedingly well. It is evident that this type of stylus holder has other applications.

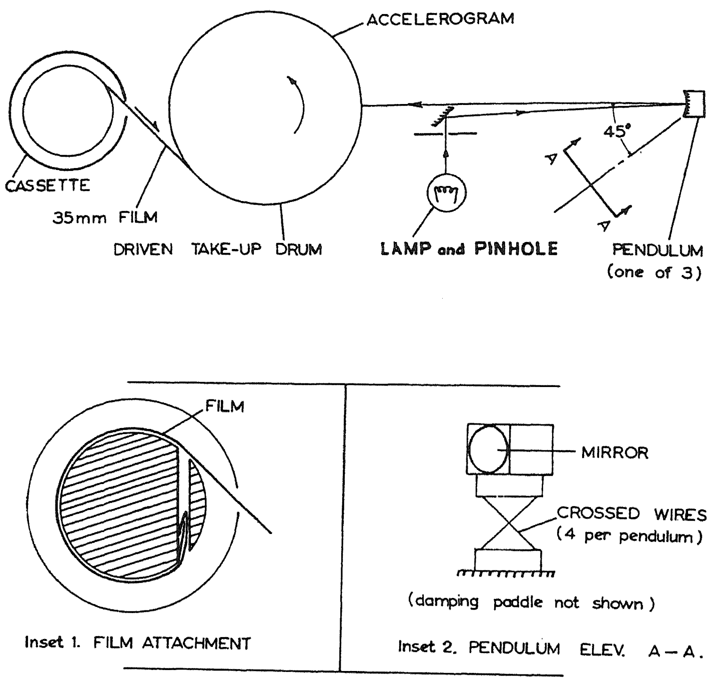

Fig 1. SCHEMATIC PLAN of 3-COMPONENT ACCELEROGRAPH.

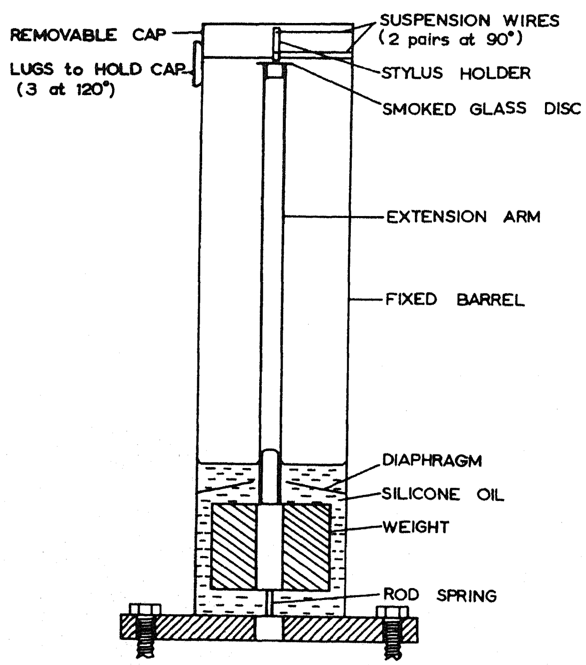

Fig. 2 SCHEMATIC ELEVATION of TWO-COMPONENT PEAK-READING ACCELEROGRAPH.

Fig. 3 SITES of "PEAK-READING" ACCELEROGRAPHS.

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QUESTION BY: D.S. CARDER - U.S.A.

How many traces are on a single 35mm film? Also, would it not be convenient to place a relative time reference on the film?

AUTHORS' REPLY: There are three active traces and a straight-line reference trace on a single width of unperforated 35mm film.

QUESTION BY: R.J.P. GARDEN - NEW ZEALAND

1. Does the 3-component accelerograph locate the event in time?
2. Would the absence of a time record not be a disadvantage in recording a long series of frequent shocks such as recently occurred at Taupo, N.Z.

QUESTION BY: H.T. HALVERSON - U.S.A.

Is real time on the accelerogram?

AUTHORS' REPLY: Sensitivity and good discrimination are achieved since the traces are sharp and fine, 0.075 mm. Considerable extra cost would be involved in supplying time markers on the film. The times of occurrence of earthquakes of engineering significance are normally known from records of seismological stations.