A COMPARISON OF RECORDS FROM THE LINEAR STRAIN AND PENDULUM SEISMOGRAPHS

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geology at the California Institute of Technology

1937

Willard Dickison Pye

A COMPARISON OF RECORDS FROM THE LINEAR STRAIN AND PENDULUM SEISMOGRAPHS

\- o -

Instruments used in the Study.

The linear strain seismograph and its action has been described by Benioff (1). Essentially the instrument consists of two piers 20 meters apart in a north-south direction. A rod is connected rigidly to the southern pier and extends to within a short distance of the northern one. At equal intervals along the rod are supports which permit only longitudinal movement of the rod. Attached to the northern pier is an electromechanical transducer (2). The rod is insulated with asbestos, and the whole instrument is placed in a long insulated tube to reduce temperature effects on the rod.

An incoming wave from an earthquake produces a variation in the separation of the piers, which causes a change in the separation of the free end of the rod and the northern pier. This sets up an induced e.m.f. in the transducer proportional to the velocity with which the displacement takes place. The induced e.m.f. activates a galvanometer, the deflection of which is recorded photographically.

There is no damping on the rod, so that it behaves essentially as a rigid body (1). Its period is approximately 0.014 seconds. The period of the galvanometer can be varied at will. By using the transducer one or more galvanometers can be run from the same instrument, thus making it possible to record with both a long period and short period galvanometer simultaneously.

The pendulum instruments recording varied somewhat, but in general consisted of East-West and North-South short period Wood-Anderson Torsion seismometers; long period East-West and North-South seismometers either of Wood-Anderson or Benioff types; and long and short period vertical torsion or Benioff seismographs. In addition a strong motion seismograph and occasionally other experimental instruments were recording.

Shocks Studied

For this investigation it was though best to use records of shocks which would make the characteristics of the instruments stand out. For this reason shocks were selected having directions of focus as nearly parallel, at right angles, and at 45° to the axis of the strain seismograph as possible, and yet have sharp impulses. Those shocks which best satisfied these conditions were the following:

Shock	Date	Δ	Approx. Dir. to Shock
Panama	7-17-34	42°	S 45° E
Baffin Bay	11-20-34	46°	N 45° E
Japan	3- 2-33	75°	N 45° W
New Guinea	9-19-35	104°	W
India	1-15-34	115°	N 45° W
Baluchestan	5-30-35	117°	N 45° W
Sumatra	12-27-35	135°	N 45° W

In addition various other records were more briefly examined both of distant and local shocks.

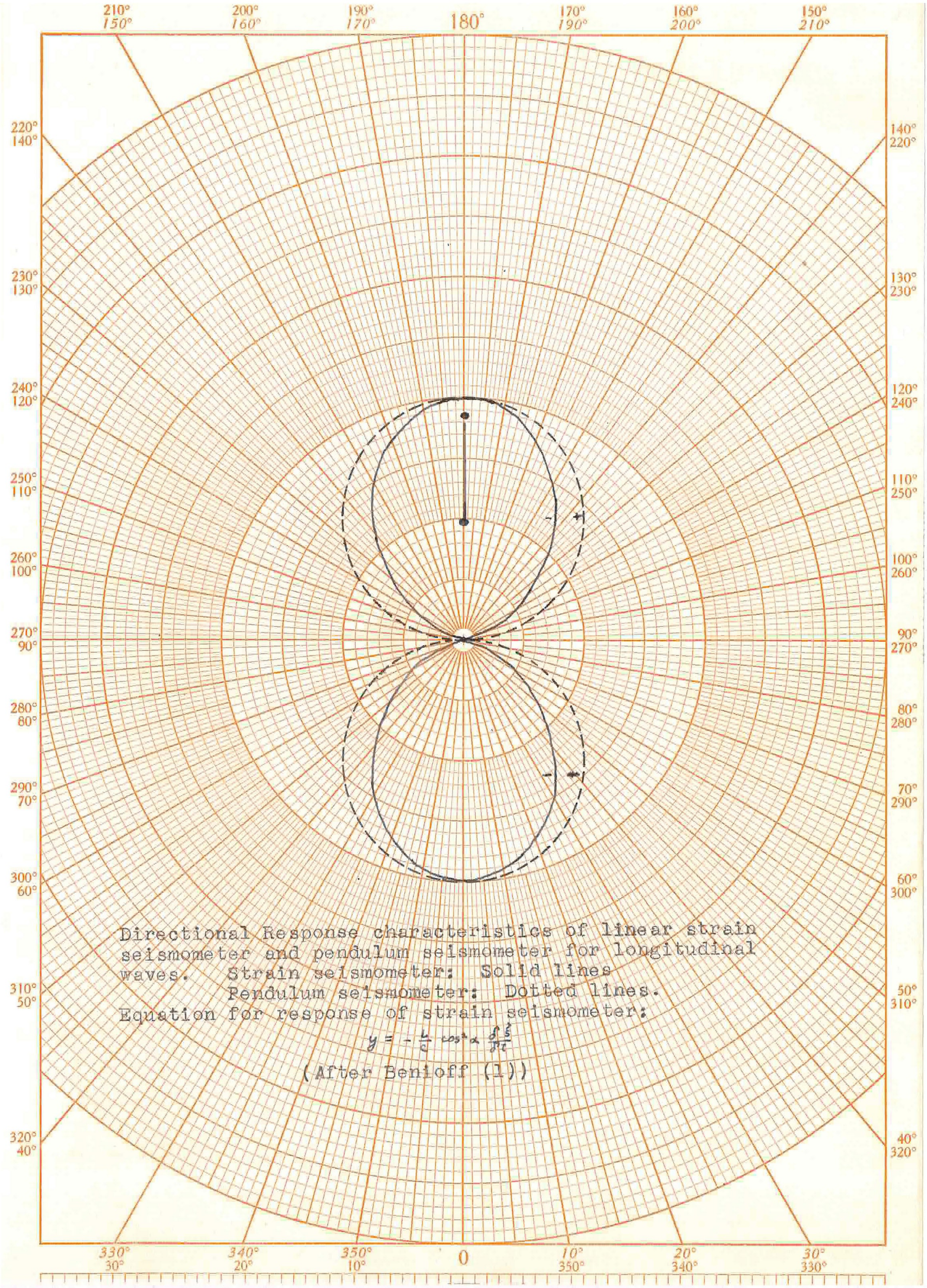
Response Characteristics

Longitudinal Waves.

The response of the strain seismograph for P-waves is maximum when the direction from the shock to the station is parallel to the axis of the instrument, and a minimum when at right angles. Thus there are two directions of maximum, and two directions of minimum response. This is the same type of response as given by a pendulum instrument except that for the strain instrument the response is identical for shocks originating 180° apart, while for pendulum instruments the response is reversed in direction.

The incoming waves from the New Guinea shock of 1935 arrived almost at right angles to the axis of the strain instrument. Here the early part of the record does not have character, although it shows distrubance. No sharp impulses are found. Small amplitude waves are also found on the shorter period pendulum North-South instrument, but are not as sharp as on the strain. This is largely due to the poorer focus of the light beam and lower sensitivity. On the East-West instruments the impulses come in much more distinctly than on any of the North-South instruments. The East-West seismographs are all shorter period instruments than the strain seismograph so possibly would record the shorter period P-waves better. The short period torsion East-West and North-South instruments have nearly the same characteristics and these show but little difference in amplitude of the recorded waves although there is more character to the East-West torsion record than the North-South one.

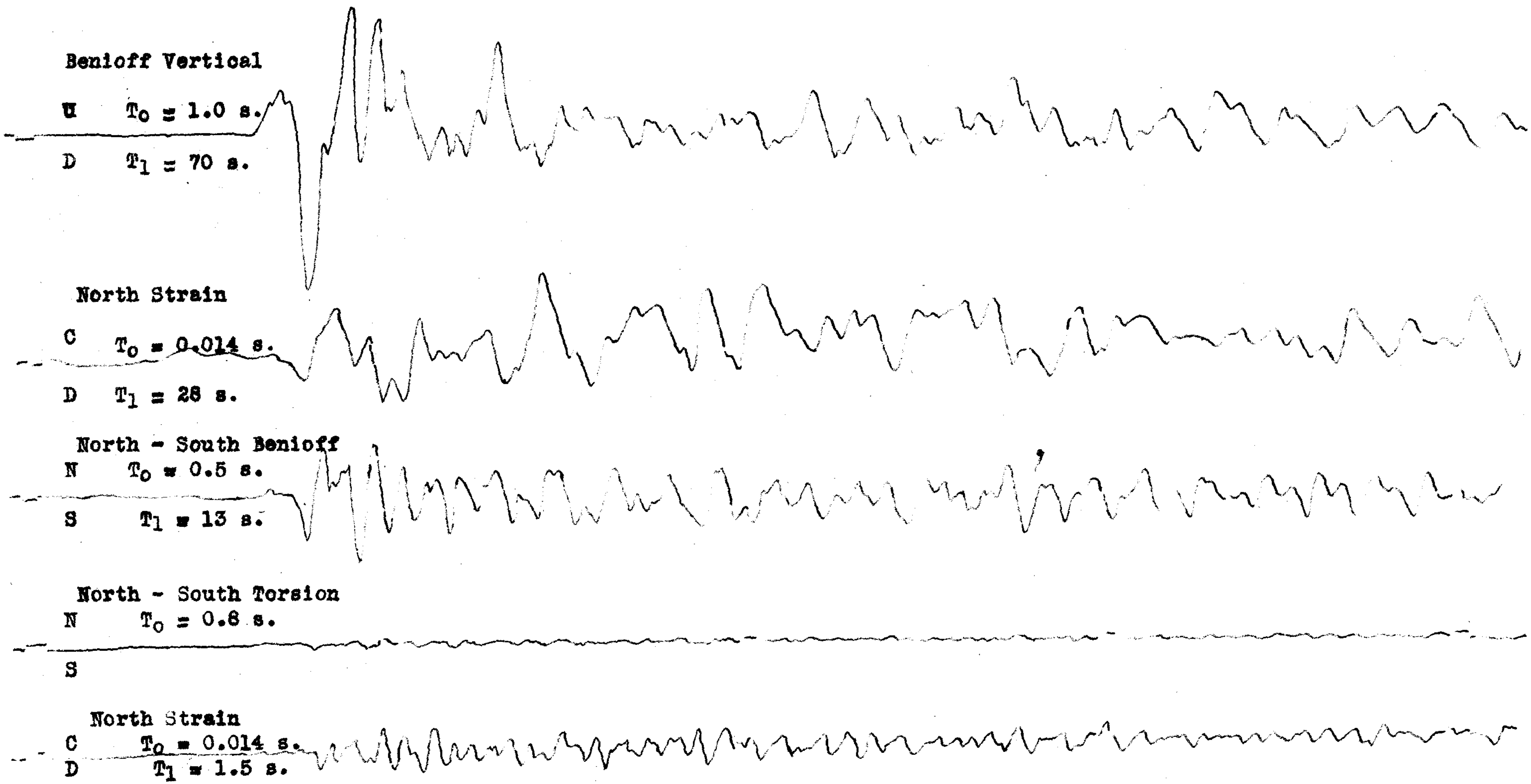
The other shocks make directions of about 45° to the axes of the instruments. They all showed about equal



Directional Response characteristics of linear strain seismometer and pendulum seismometer for longitudinal waves. Strain seismometer: Solid lines
Pendulum seismometer: Dotted lines.
Equation for response of strain seismometer:

$$y = -\frac{L}{c}\cos^2\alpha\frac{\partial\xi}{\partial t}$$

(After Benioff (1))



Part of seismogram of Panama earthquake of July 17, 1934 (= 42°), comparing the recordings on various instruments. Tracing starts at 17h 44m 00s with a timing correction of -24 seconds.

response on the North-South and East-West torsion and pendulum instruments, and good strength on the strain instrument. This is true even for the more distant shocks where the angle of emergence becomes greater and the horizontal component less. There is, of course, a decrease in amplitude with this increasing distance, therefore the more distant shocks naturally become less strong than those with a closer epicenter.

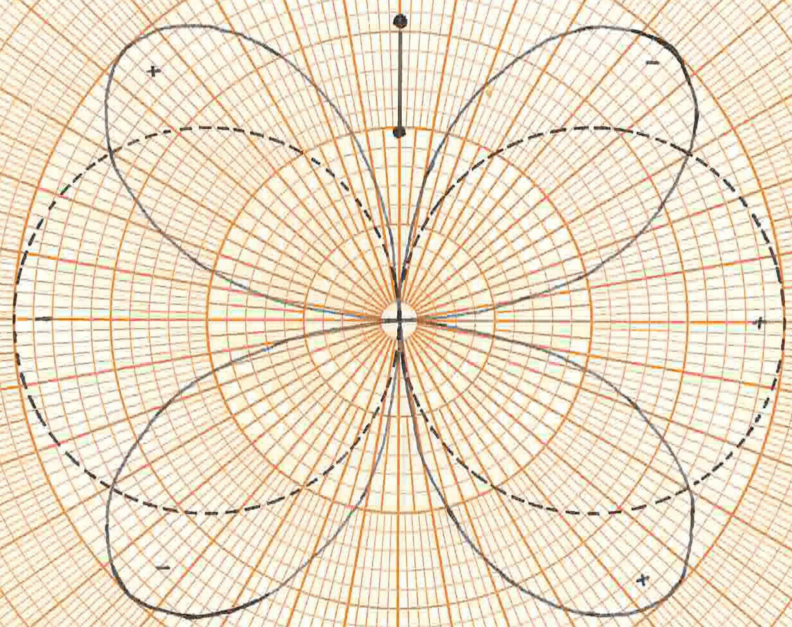
If the characteristics of the vertical, north-south, and east-west seismographs are nearly the same, then by taking the ratio of the amplitudes and the direction of movement, the direction of the shock can be determined. The strain seismograph can likewise be used with the east-west and north-south pendulum seismographs to determine the direction of the focus. The ratio of the amplitudes and direction of displacement on the normal seismographs gives the direction the earth is moving along the line which joins the epicenter with the station. It does not tell on which end of the line the shock occurs. The strain instrument records compression and dilatation of the earth. Therefore, by determining which occurs in the initial phase on the strain seismograph and comparing with the pendulum instruments, the direction of the focus can be determined.

This analysis of ground movement can also be applied to other emerging phases, but only when the instruments have become essentially quiet, or when the emerging phase is sharp enough so as not to be altered greatly by other minor movements of the instrument. A comparison of different shocks that have sharply recorded components shows that the response of the strain and pendulum instruments can thus be correlated if instrument characteristics are similar enough.

Transverse Waves.

Unlike the pendulum seismometers which have their maxiumum response when the direction of propagation of the wave is perpendicular to the instrument orientation, and minimum response when they are parallel, the strain seismograph has its maximum response when the direction of wave propagation and axis of the instrument are at 45° to each other. This gives four directions of maximum and four of minimum response, the four of minimum response being parallel and perpendicular to the direction of wave propagation. (1)

In general, the response to the S-waves for the strain seismograph is complicated and needs caution in interpreting. By the time the S-waves arrive, the instrument is in a disturbed state and interference may seriously influence the appearance of the wave as it is recorded. Besides the directional effect, there is the effect of the plane in which the wave is vibrating. A transverse wave that is vibrating in a vertical plane will produce the same effect on the horizontal strain instrument as a longitudinal wave traveling the same direction but the angle of incidence rotated 90°. However, if conditions are favorable on the north-south strain seismometer, and there is a component of motion



Directional response characteristics of linear strain seismometer (solid line) and pendulum seismometer (dotted line) for transverse waves.

Equation for response of strain seismometer:

$$y = \frac{L}{c} \sin\alpha \cos\alpha \frac{\delta\xi}{\delta t}$$

(After Benioff (1))

of the ground in the north-south direction, then the strain instrument will record this as a dilatation or compression.

As mentioned earlier, the New Guinea earthquake has a focus nearly due west of Pasadena, and as a result should record no S-waves on the strain seismograph. As with the later P-waves, S-waves are recorded but are much weaker than those recorded from shocks which make a direction of about 45° to the axis of the instrument. The north-south pendulum instrument records these waves clearly. The explanation for this recording of both the P- and S- waves on the strain instrument probably lies in the fact that the shock did not originate due west of Pasadena, so had a slight north-south component, or motion of the instrument is not due to north-south motion of the ground.

Surface Waves.

Since the Love and Rayleigh waves are propagated at the surface of the ground, the motion of the surface of the ground is the true motion, with no distortion as is found in the ground motion due to the angle of incidence of the P- and S- waves. Thus the instruments give a true picture of the wave for the surface waves.

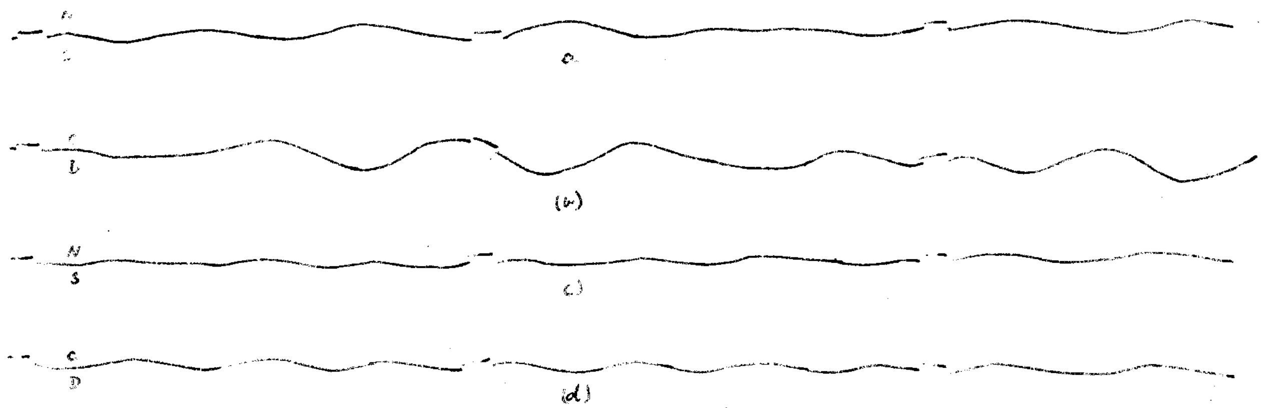
The Rayleigh waves travel slower than the Love waves. The motion of a particle is elliptic and retrograde with the major axis of motion usually vertical. The ratio of the vertical amplitude to the horizontal amplitude of motion is about three to two, and there should be no component of motion making an angle with the direction of propagation.

The Love waves travel faster than the Rayleigh waves, and have as a limit the velocity of the S-waves. The form is that of a shear wave which lies in the horizontal plane. Theoretically they should have no vertical component, however, they commonly have a small one similar to the small component perpendicular to the direction of propagation for the Rayleigh waves (3).

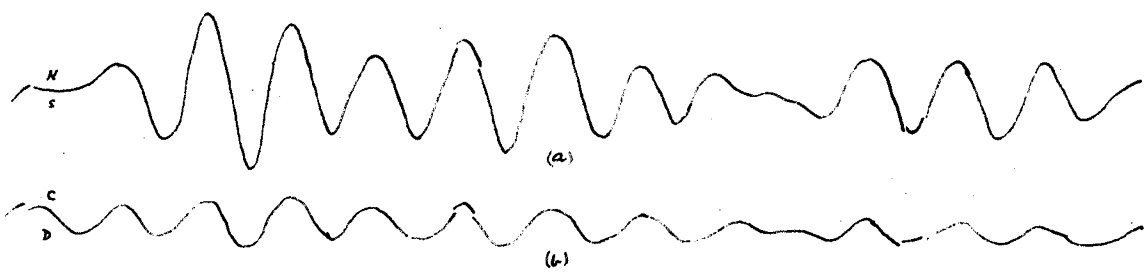
On pendulum instrument records, the surface waves are distinguished by this difference in strength of vertical components.

On the strain instrument, especially the one recording with the long period galvanometer, all surface waves are well recorded no matter from what direction they originate. Since the vertical component is dominant for the Rayleigh waves they tend to be recorded with far less amplitude than the Love waves. The Rayleigh waves act similar to longitudinal waves so far as response characteristics on the strain seismograph are concerned. The Love waves, on the other hand, have a response on the strain seismograph similar to the transverse waves with the same directional characteristics.

Since the surface waves have a response on the strain seismograph similar to that given by the P- and S- waves, by using shocks which had surface waves which had traveled around both arcs of the earth a check on the theoretical directional response was hoped for. Most of the shocks did not record the waves traveling both directions or else other disturbing factors made comparison impossible. On the Baluchistan record the strain and pendulum instruments gave records which were 180° out of phase, e.i. when the pendulum moved north or up, the strain instrument moved



Part of seismogram of Baluchistan earthquake of May 30, 1935 ($\Delta = 117^{\circ}$). a and c recorded by short period N - S torsion seismograph (T_o = 0.8 sec.), and b and d recorded by short period strain seismograph (T_o = 0.014 sec., T_g = 1.5 sec.). a and b represent surface waves traveling around the short arc (arriving from NW) which are 180° "out of phase", and c and d are the same waves (?) traveling around the long arc (arriving from SE) which are "in phase."
a + b Tracings start at 14h 39m 00s P.S.T. with a timing correction of -15 seconds. Breaks are minute marks. c and d tracings start at 15h 51m 00s P.S.T. with the same timing correction.



Part of seismogram of Panama earthquake of July 17, 1934 ($\Delta = 42^{\circ}$), recorded by long period N - S Benioff seismograph (T_o = 0.5 sec., T_g = 13 sec.) and b recorded by short period strain seismograph (T_o = 0.014 sec., T_g = 1.5 sec.). These are surface waves arriving from the SE and are "in phase." The record for the long period strain (T_g = 28 sec.) is identical with that for the short period strain for these waves.

Tracing starts at 18h 32m 00s P.S.T. with a timing correction of -24 seconds. Breaks are minute marks.

down indicating a dilatation, when traveling along the shorter arc, and "in phase" when traveling along the longer arc. This was also true of the India earthquake. Theoretically the pendulum instrument has reversed direction of response and the strain instrument remained the same, but difficulty in positively identifying corresponding surface waves makes proof difficult. There is also the possibility that the waves on opposite sides of the epicenter may not have been in phase in the first place.

Surface waves from the Japanese earthquake were not recorded on the torsion and pendulum instruments around both arcs, but on the strain instrument W_{IV} and preceeding waves are found. The waves as they come through Pasadena apparently caused the same direction of movement of the strain instrument each time.

Local Shocks.

The strain seismograph with the long period galvanometer is insensitive to the short period waves found in a local shock, but when it is equipped to record with a short period galvanometer, it records the short period waves fully as well as a pendulum instrument of short period.

General Observations.

If a long period galvanometer is used for recording, the strain instrument is very usefull for the study of the long surface waves. As indicated before, on the 1933

Japanese records from the strain instrument W_{IV} waves were recorded with good amplitude, but these did not show up at all on the pendulum instruments. By using the electromechanical transducer a short period galvanometer can be run from the same instrument and thus the shorter period waves can be recorded also with great sensitivity. The Panama shock showed that even with a short period galvanometer on the strain instrument the long period waves could be recorded on it equally as well as on a pendulum instrument of about eight times its period.

Recommendations.

This study has brought out several possible improvements in the set up and recording of the instruments.

(1) Since much of the value of the strain seismograph is derived from the accurate comparison of its records with those of the pendulum seismographs, a great improvement would consist of having the strain instrument recording directly above or below (on the same record) a pendulum instrument of the same characteristics.

(2) For the study of the short period waves, a short period galvanometer recording one minute as 60 millimeters is best, but for a study of the long periods, a long period galvanometer recording one minute as 15 millimeters is better than one minute as 60 millimeters.

(3) The instruments being used to give components of motion should have the same characteristics.

(4) An east-west strain instrument of type similar to the north-south strain instrument would be very valuable

in the study of the horizontal motion of the ground. Likewise a vertical strain seismograph for study of vertical strains would be a valuable aset in this work.

Conclusions.

The advantage of the strain seismograph over the pendulum seismographs for the study of local shocks and short period waves is little. Its most important use is in the study of the longer period waves.

If a good vertical instrument were designed and built together with an east-west strain instrument, then these recording on both long and short period galvanometers could be used more effectively than the normal seismographs in some cases.

In regions with as many seismological stations as California, the additional information which they give to a single station would not repay the expense of building and maintaining such a set of instruments in addition to a set of pendulum instruments. For a specialized study of waves, they would give certain additional information which would be of importance.

In connection with the preparation of this thesis the writer takes pleasure in acknowledging the help and advice received from Dr. B. Gutenberg, Dr. C. F. Richter, and Dr. H. Benioff under whose direction this work was conducted.

References

1. Benioff, Hugo: A linear strain seismograph, Bull. Seism. Soc. Am. 25, 1935, pp. 283 - 309.

2. Benioff, Hugo: A New Vertical Seismograph, Bull. Seism. Soc. Am. 22, 1932, pp. 155 - 169.

3. Macelwane, J. B.; and Sohon, F. W.: Introduction to Theoretical Seismology, Pt. I, Geodynamics, 1936.

DATA

Panama

July 17, 1934

Δ = 42°

Approx. Dir. from Pasadena: S 45° E

Phase	Time h	Time m	Time s	Pendulum Instruments U - D T_s	U - D T_1	E - W T_s	E - W T_1	N - S T_s	N - S T_1	Motion	Strain T_s	Strain T_1	Remarks
P_1	17	44	16	U	U	?	W	N?	N	[illegible]	C	C	
P_2			34	D?	D	E	E	S	S	[illegible]	D	D?	
P_3			48	U	U	E	E!	S	S	[illegible]	C?	D?	Not sharp
P_4		45	06	D?	D?	-	E?	N?	N	[illegible]	C	C!	Not distinct
PP			52	D	U!	E	E	S?	S	[illegible]	D	D	
PcP		46	05	D	U	E?	E?	S?	S!	[illegible]	D	D!	
PP_2?		47	38	U?	U?	W?	-	-	N	[illegible]	C	C!	
PcS		49	58	U	D	E?	E?	N	N	[illegible]	C	C	
S_2		50	34	D	D	W?	W?	S?	S	[illegible]	D	C	
S_6?			40	D!	D!	W	W	S	S!	[illegible]	-	D	Sharp
ScS		54	33	-	D	-	W?	S	S!	[illegible]	-	D!	Sharp

Baffin Bay

November 20, 1934

Δ = 46°

Approx. Dir. from Pasadena: N 45° E

Phase	Time h	Time m	Time s	Pendulum Instruments U - D T_1	E - W T_1	N - S T_1	Motion	Strain T_1	
P_1	15	29	57	U?	W	S	[illegible]	C	
P_2		30	11	D	-	N	[illegible]	C	Not distinct
PcP		31	25	D	E	S	[illegible]	C?	Not distinct
PP		31	54	U	W	S	[illegible]	C	
PPP		32	34	D	E	N	[illegible]	D?	Strain not sharp
PcS		35	20	-	E	S?	[illegible]	D	
eS		36	37	-	E	N	[illegible]	D	Not shaprp
ScS		39	45	-	-	N	[illegible]	D?	

New Guinea — September 19, 1935

$\Delta = 104^{\circ}$ — Approx. Dir. from Pasadena: West

Phase	Time h	Time m	Time s	Pendulum Instruments U - D T_1	E - W T_1	N - S T_1	Motion	Strain T_1	Remarks
eP	18	00	23	U	E	N?	[illegible]	C?	N-S & Strain no definite movement.
P			43	U	E	*	→	-	Do.
ePP		04	30	U	E	-	→	-	Do.
SKS		11	23	-	W	S	[illegible]	C	Not sharp on Strain
iP'P'		25	52	U	E	N	[illegible]	D	E-W not sharp
iPS		14	05	D	E	N	[illegible]	D	

India — January 15, 1934

$\Delta = 115^{\circ}$ — Approx. Dir. from Pasadena: N 45° W

Phase	Time h	Time m	Time s	Pendulum Instruments U - D T_1	E - W T_1	N * S T_1	Motion	Strain T_1	Remarks
P	00	57	44	D	-	-		C	
PP	01	03	08	U?	E	N	[illegible]	C	Not sharp
PS		12	47	D	E	N	[illegible]	D	
PPS ?) PS ?)		13	10	U	E	S	[illegible]	C	
PPS		13	21	U	E	S	[illegible]	D?	
SSS		23	41	U	W?	N	[illegible]	D	

Sumatra December 27, 1935

$\Delta = 135^{\circ}$ Δt = -6 Approx. Dir. from Pasadena: N 45° W.

Phase	Time			Pendulum Instruments				Strain	Remarks
				U - D	E - W	N - S			
	h	m	s	T_l	T_l	T_l		T_l	
(iP! (Diffracted	18	54	48	D	E	Light out		D	N? on T_s
iPKS) PP)		58	22	D?	E			C	S on T_s
i SKSP	19	07	34	D	E?			D	
i PPS		09	17	D	W			C?	Not sharp on strain.
i SS		15	35	-	W			C	
i SSS?		21	28	U	E			C	

Notes: Strain D = dilatation

C = compression

T_l = long period instrument

T_s = short period instrument

? Phase not sharp or direction of movement uncertain.

! Phase sharp.