CALIFORNIA INSTITUTE OF TECHNOLOGY

EARTHQUAKE ENGINEERING RESEARCH LABORATORY

THE WILMOT SURVEY TYPE STRONG-MOTION EARTHQUAKE RECORDER

by

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A REPORT ON RESEARCH CONDUCTED UNDER
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Summary

A simplified instrument for the direct measurement of one point on the response spectrum of the ground motion caused by strong-motion earthquakes is described, and the theory of operation is developed. Determinations of the physical characteristics of two test instruments of a standardized design suitable for large scale production and installation are discussed. Direct comparisons between the instrument results and the spectrum analysis of base accelerations are given, and the conclusion is reached that the device in its present form is suitable for the contemplated application to strong-motion earthquake measurement.

Introduction. The Wilmot Survey Type Strong-Motion Earthquake Recorder is an instrument which measures directly one point on the relative velocity response spectrum curve. The original prototype of the device was developed by the United States Coast and Geodetic Survey based on design data from the Earthquake Engineering Research Institute, and later design development and test work was carried out at the Earthquake Engineering Research Laboratory of the California Institute of Technology under a program sponsored by the National Science Foundation. The final production design development and construction of a standardized model was the work of the Wilmot Engraving and Instruments Company.

For the design of earthquake resistant structures it would be desirable to have complete acceleration-time records for the ground motions associated with destructive earthquakes. Such information is obtained from the strong-motion accelerometer program of the U. S. Coast and Geodetic Survey. The complexity and expense of such time-recording accelerometers have, however, made it impossible to provide as complete an area coverage as would be desirable, and hence there has been an incentive for the development of a simpler device which could be installed in relatively large numbers.

The present instrument does not attempt to measure either the displacement or the acceleration of the ground, but gives directly a measure of the response of a typical structure to the ground motion. The device can thus be looked upon as a dynamic model of a typical structure, and the instrument has been designed to have the same basic dynamic properties of natural period and damping as an average structure. By supplementing the results obtained from a number of the present instruments with information obtained from the existing strong-motion accelerometers and that contained in the complete response spectrum curves calculated for past earthquakes, much useful information for the design engineer can be made available.

It should be noted that the instrument has been designed around the measurement of one particular type of ground motion - that associated with strong earthquakes in the Pacific Coast region. If the instrument is used for other purposes, as, for example, the measurement of ground motions caused by blasts, some modification of the basic instrument parameters may be desirable.

Basic Design Principles. The instrument consists of a free conical pendulum which can move in any horizontal direction. The support point of the pendulum acquires the horizontal motion of the ground, and the resulting angular deflections of the pendulum are recorded by a scriber on a spherical smoked glass. Since the motion in a horizontal plane is traced out as a permanent record, the sequence of events can be followed even though no time-recording is employed. In this way much more information than would be obtained from an indication of maximum displacements alone can be secured by a very simple means.

A general view of the instrument showing its major features is shown in Fig. 1a, and a dis-assembled view is given in Fig. 1b. Complete working drawings of the device are given in Appendix I.

In Fig. 2a is shown the general configuration of the compound pendulum forming the structural model. Fig. 2b shows the simplest dynamically equivalent model, and gives the notation to be employed in the following analysis.

The equation of motion describing the angular displacement φ of the damped compound pendulum whose point of support is given a horizontal acceleration $\ddot{y}(t)$ is, assuming motion in one plane:

$$\ddot{\varphi} + \frac{cb^2}{I_o}\dot{\varphi} + \frac{mga}{I_o}\varphi = -\frac{ma}{I_o}\ddot{y}(t)$$

where:

m = total mass of the pendulum

a = distance from center of rotation to center of mass

b = distance from center of rotation to damping force

I_o = moment of inertia about a transverse axis through the center of rotation

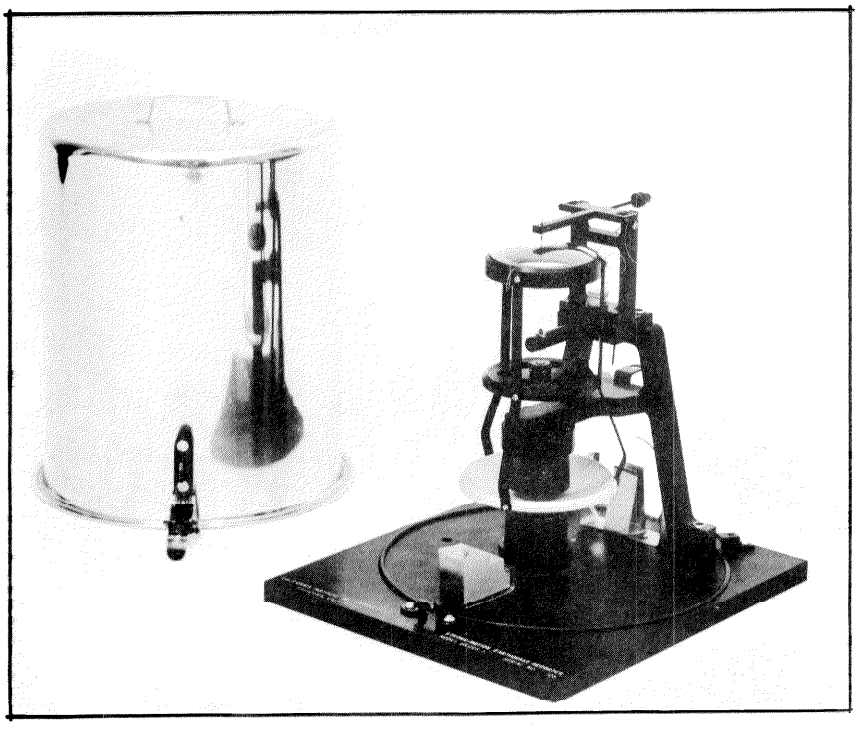


Fig. 1a General View of the Wilmot Instrument with its Protective Cover

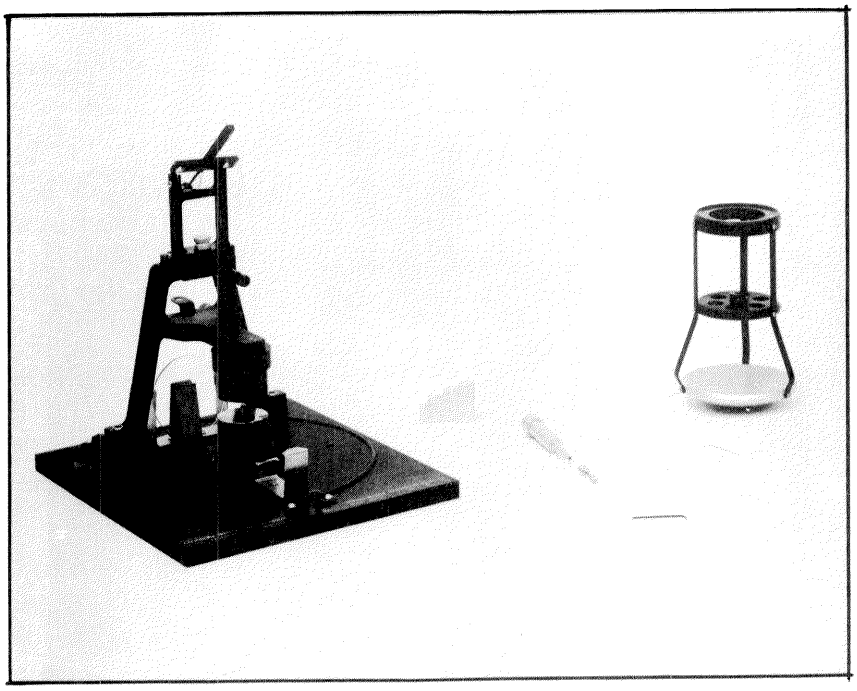


Fig. 1b Dis-assembled View of the Wilmot Instrument

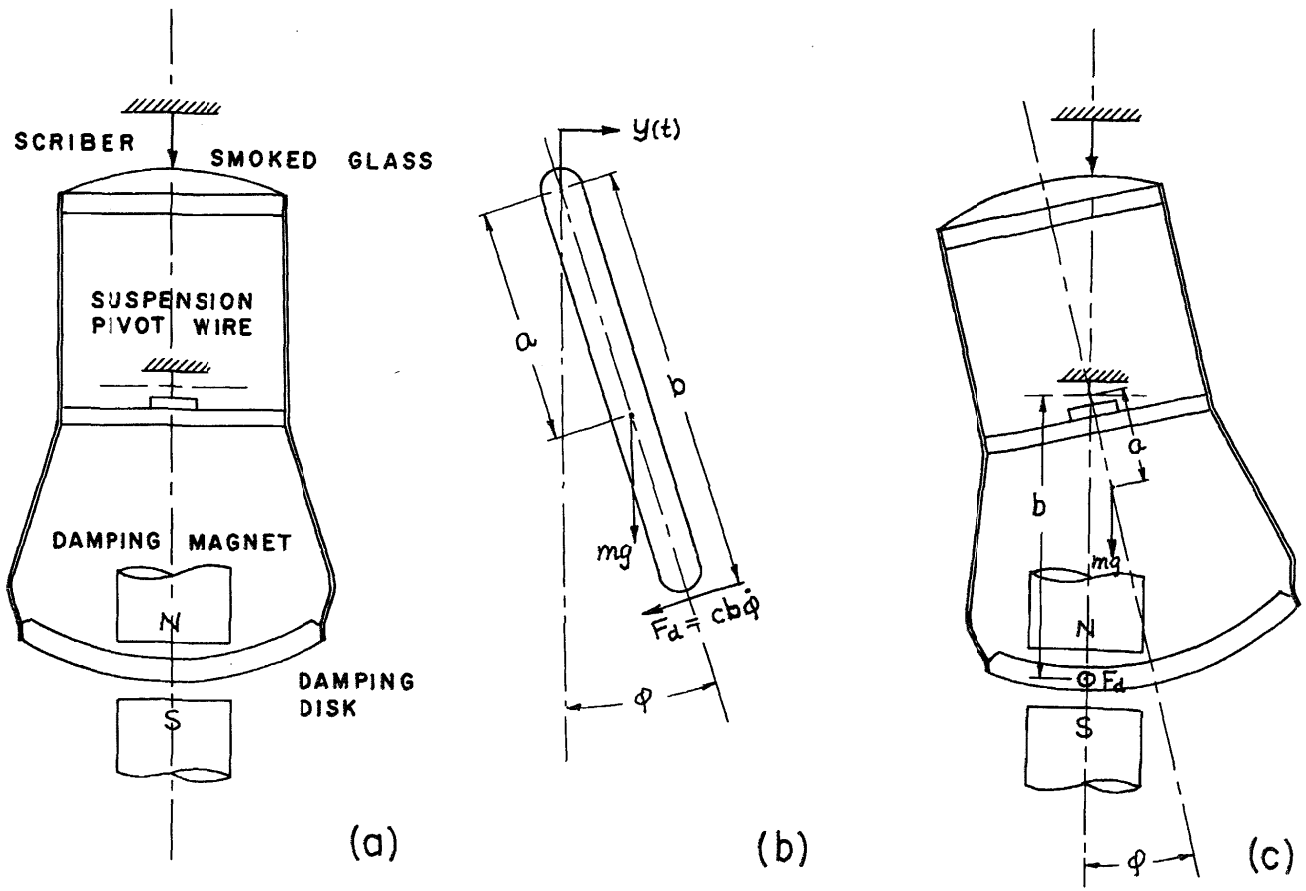


FIG. 2. SCHEMATIC DIAGRAM OF THE WILMOT INSTRUMENT

g = acceleration of gravity

c = viscous damping coefficient. Damping force = $cb\dot{\varphi}$

The solution of this equation for the vertical angle of the pendulum is:

$$\varphi = \frac{2\pi}{gT\sqrt{1-n^2}} \int_0^t \ddot{y}(\tau)\, e^{-\frac{2\pi n}{T}(t-\tau)} \sin \frac{2\pi}{T}\sqrt{1-n^2}\,(t-\tau)\, d\tau$$

where:

$$T = 2\pi\sqrt{\frac{I_0}{mga}}$$ = undamped natural period of the pendulum

$$n = \left(\frac{c}{c_c}\right) = \frac{cb^2}{2\sqrt{mgaI_0}}\ ;$$ c_c = damping coefficient for critical damping

For small damping (n = 0.10 for this particular instrument), the solution simplifies to:

$$\varphi = \frac{2\pi}{gT} \int_0^t \ddot{y}(\tau)\, e^{-\frac{2\pi n}{T}(t-\tau)} \sin \frac{2\pi}{T}(t-\tau)\, d\tau$$

By definition, the maximum relative velocity response spectrum is given by (refs. 1 and 2):

$$S_v = \left[\int_0^t \ddot{y}(\tau)\, e^{-\frac{2\pi n}{T}(t-\tau)} \sin \frac{2\pi}{T}(t-\tau)\, d\tau\right]_{max}$$

Therefore:

$$\varphi_{max} = \frac{2\pi}{gT} S_v$$

and hence the maximum angle of the pendulum measures directly the response spectrum.

The particular design parameters for the instrument (T = 0.75 sec, damping = 10% critical) were selected after a careful study of the complete response spectrum curves for past earthquakes and of the dynamic characteristics of typical building structures (Ref. 2). It has been concluded that this particular point would be the most useful single point for defining the approximate magnitudes of the complete spectrum curves in the region of most structural interest. This conclusion has recently been re-inforced by the results of an analysis of strong-motion accelerometer data obtained for the San Francisco earthquake of March 22, 1957. (Ref. 3)

The dimensions of the pendulum are such that a full scale deflection represents a response spectrum magnitude of about 2 ft/sec. This is as large a value as would be expected except possibly in the immediate vicinity of a major earthquake ($\simeq$ 8 on the Gutenberg-Richter magnitude scale).

One possible difficulty which might be expected with the instrument in its present form may be seen by referring to Fig. 2c. If, while the pendulum is deflected through a large angle in one plane, a large motion should simultaneously occur in the perpendicular plane, the resulting damping force would exert a torque about the suspension wire which might excite torsional oscillations of the pendulum. If a significant amount of energy were to go into this torsional mode of oscillation, the amplitudes of the modes in vertical planes might be appreciably reduced. A complete analysis of this problem would be expected to be very complex, because at the large angles at which this phenonema would be important, non-linear effects might also be significant. An approximate analysis of the order of magnitude of this torsional moment can easily be made, however, along the following lines.

From Fig. 2c we have:

Damping torque causing torsional motion = T_D

$$T_D = F_d \, b \sin\varphi = c b^2 \dot{\varphi} \sin\varphi$$

Gravity restoring torque = $T_G = mga \sin\varphi$

Thus

$$\frac{T_D}{T_G} = \frac{c b^2 \dot{\varphi}}{mga}$$

Since $$n = 0.10 = \left(\frac{c}{c_c}\right) = \frac{c b^2}{2\sqrt{mga I_o}},$$ we have:

$$c = \frac{0.2\sqrt{mga I_o}}{b^2}$$

Also:

$$\dot{\varphi}_{max} = \frac{2\pi}{T}\varphi_{max} = \varphi_{max}\sqrt{\frac{mga}{I_o}}$$

Thus:

$$\frac{T_D}{T_G} = \frac{0.2\sqrt{mga I_o}}{b^2} \cdot \frac{b^2}{mga}\varphi_{max}\sqrt{\frac{mga}{I_o}} = 0.2\,\varphi_{max}$$

The maximum possible angle through which the pendulum can swing is somewhat less than 30°, so in the worst case:

$$\frac{T_D}{T_G} \approx 0.1$$

and the maximum damping torque is of the order of one-tenth of the gravity restoring torque. The magnitudes of the motions caused by these torques will be directly proportional to the respective natural periods. For the mode in

the vertical plane the natural period of the instruments as tested is 0.73 seconds, while the natural period of the torsional mode is 0.83 sec. Since these values are of the same order of magnitude, we conclude that the motions associated with the torsional excitation are small compared with those in a vertical plane. This conclusion is confirmed by the overall calibration tests reported in the next section.

It should be noted that the effects of the above coupled motions could be even further reduced or eliminated by certain design changes in the instrument. If the damping disk were fixed and the magnet were attached to the moving pendulum, the twisting moment would be practically eliminated. Similarly, if the glass recording plate were fixed, and the stylus were attached to the moving pendulum so that it would scribe on the lower side of the plate, the torsional motions would not be recorded even if they should occur. Tests have shown, however, that these refinements, which would involve some other compromises in design, are not necessary for the present application.

Calibration Tests. To get an overall check on the behavior of the instrument and to assess the accuracy of the readings, an extensive set of calibration studies were made.

It was first thought that a small mechanical shaking table with a cam drive that was available in the laboratory could be modified to produce a two-dimensional horizontal acceleration typical of those to be encountered in practice. It was found, however, that this would require more of a development job than was warranted, and the hand-operated device shown in Fig. 3 was adopted. This consists simply of two $\frac{1''}{8}$ x 12" x 18" brass plates separated by four 3/4" diameter steel balls. Two variable reluctance

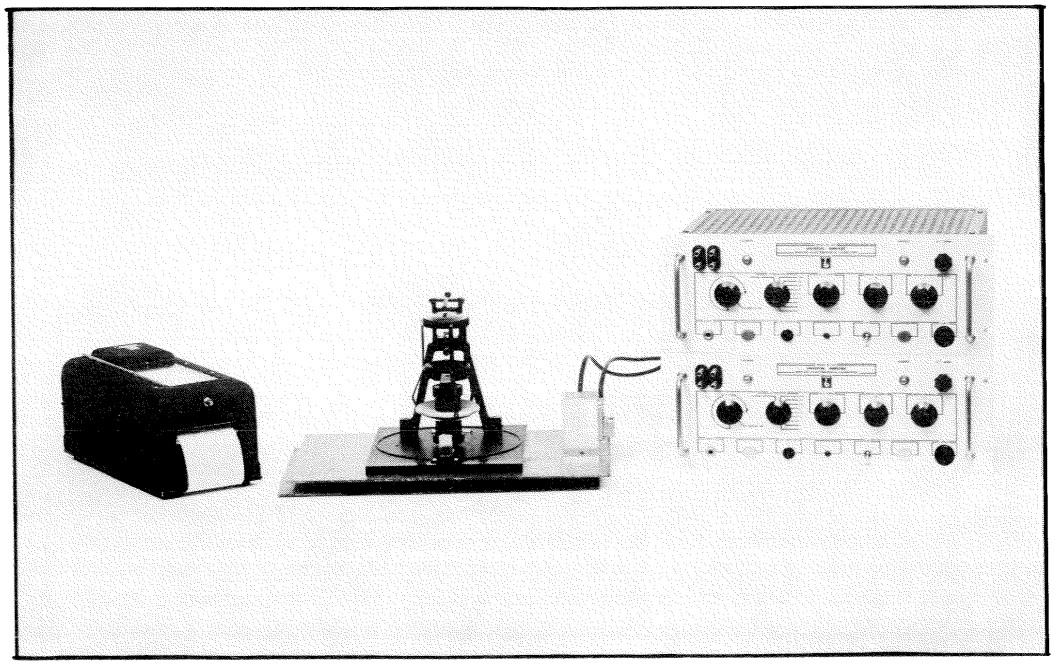


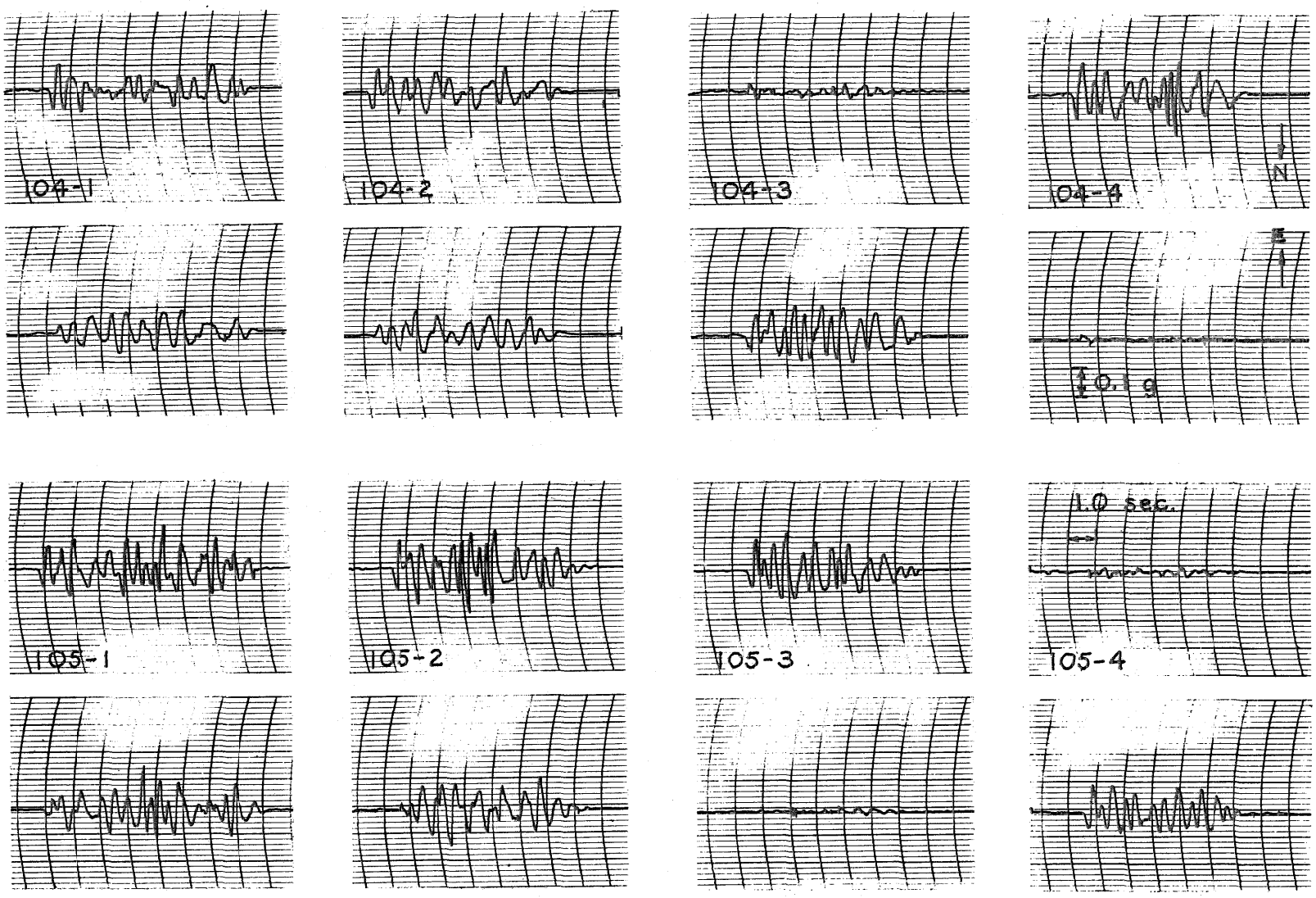
Fig. 3 General View of Test Table Arrangement for Recording Base Accelerations

accelerometers (William Miller Type 402-c) are mounted on the plate to record horizontal accelerations in two perpendicular directions, and the output of these accelerometers is recorded on a two-channel Brush ink-writing oscillograph (Lab. No. 180) using two Brush Model BL-360 carrier system and amplifier units. The table is moved by hand and the recording of the accelerometers is simultaneously noted. With a little practice, it was found that transient accelerations having amplitudes, periods, and time durations similar to those of strong-motion earthquakes could be easily produced. The accelerometers were calibrated by rotating them through 90° in the earth's gravitational field, and the calibrated attenuators on the Brush carrier system amplifier were used to set the scales.

In Fig. 4 are shown the horizontal components of acceleration for the eight tests that were completely analyzed. The Wilmot instrument was in all cases set on the brass plate with the pendulum supporting pedestal in the back or "north" position. In Fig. 4 the upper trace was in each case the N-S direction, and was recorded with accelerometer lab. no. 199 through amplifier lab. no. 271. The lower traces were E-W, recorded with accelerometer lab. no. 200 through amplifier lab. no. 270.

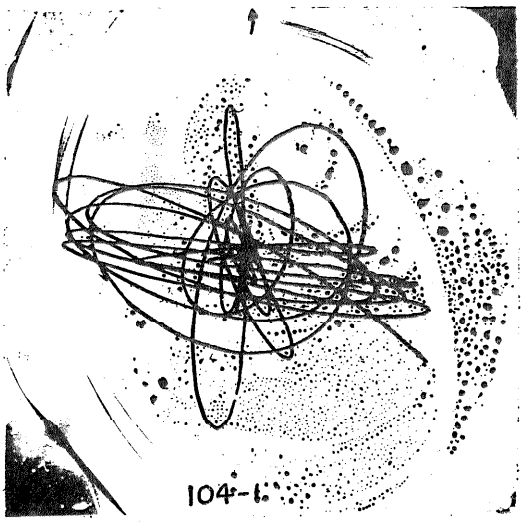
In Figs. 5a and 5b are shown the records obtained on the Wilmot instrument corresponding to the base accelerations of Fig. 4. Two Wilmot instruments, serial nos. 104 and 105, were tested. The pictures of Fig. 5 were made by using the smoked glass plate as the negative in a photographic enlarger.

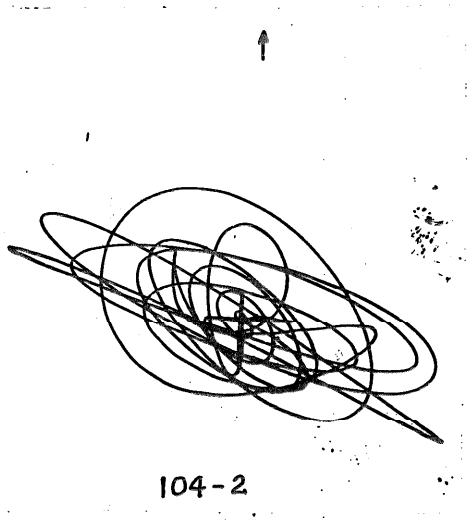
Determination of Instrument Characteristics. Tests for tilt sensitivity, damping, and period were made on the two Wilmot instruments.

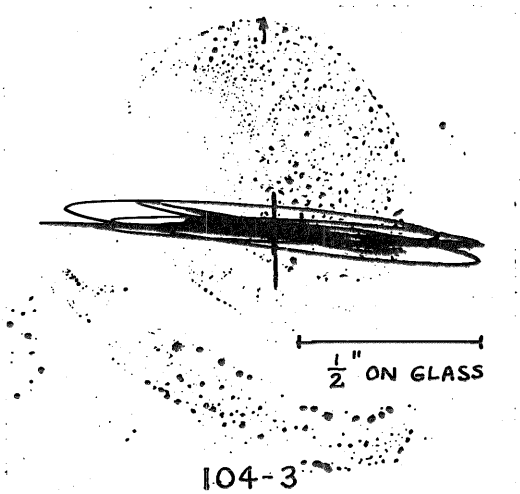


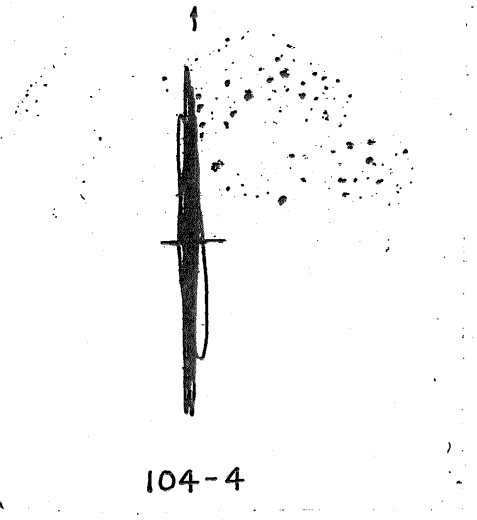
CALIBRATION ACCELERATION RECORDS

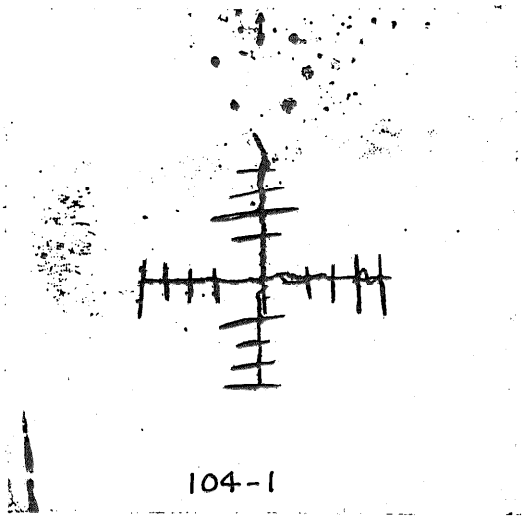
FIG. 4

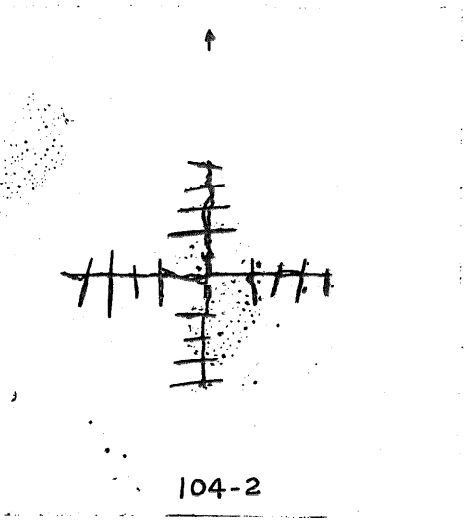






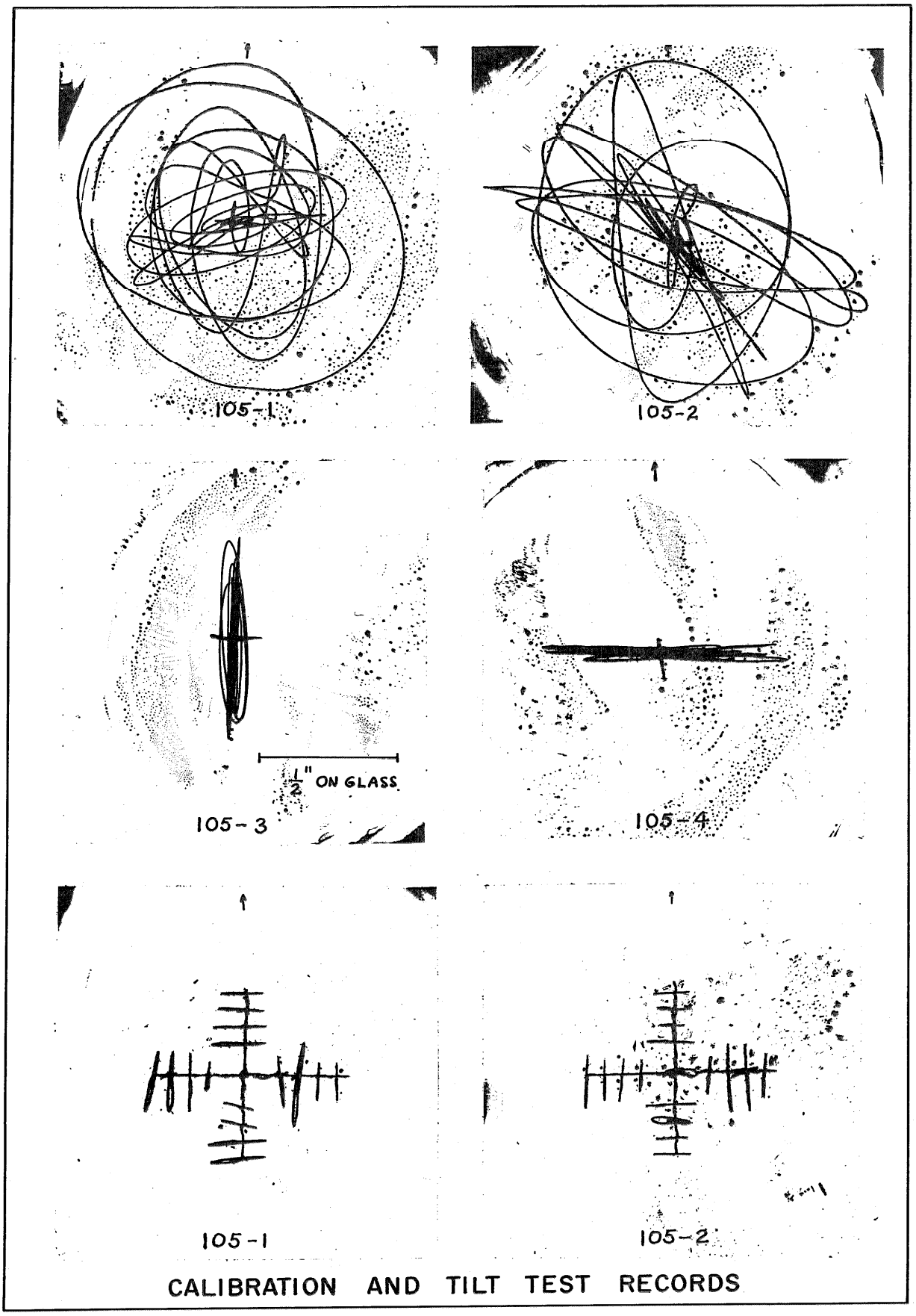






CALIBRATION AND TILT TEST RECORDS

FIG. 5a



CALIBRATION AND TILT TEST RECORDS

FIG. 5b

Tilt Sensitivity Tests. With the instrument on a level table top, the scriber assembly was adjusted to the center of the plate, using a clear glass plate having ruled center lines. With a smoked glass in place, small motions of the pendulum in the NS and in the EW direction were introduced, to mark the zero position.

Using the various steps of the small step block shown in the center background of Fig. 1b under the edge of the rectangular base plate, known angles of tilt were set into the instrument. At each step position, a small motion of the pendulum perpendicular to the tilt direction was introduced, to mark the smoked glass plate. The records obtained are shown at the bottom of Figs. 5a and b. The cumulative step heights are 1/2", 3/4", 1", and 1 1/4", and the base plate dimensions are NS - 9 7/8" and EW - 8 13/16".

The displacement on the glass plate in inches per radian tilt was calculated for all of the points shown on Figs. 5a and b, with the results given in Table I. Each entry in the table represents the average of the

Table I - Tilt Sensitivity

INSTRUMENT AND TEST NO.	TILT SENSITIVITY INCHES/RAD. Mean	RMS Deviation
104-1	2.30	0.04
104-2	2.39	0.04
105-1	2.41	0.05
105-2	2.30	0.06

sixteen points measured on each plate. No systematic variations of the tilt sensitivity were noted on any one plate for the different directions.

The variations between the two tests on the same instrument are of the same order as those between the two instruments.

It is concluded that the variations indicated in Table I, which are at most of the order of 5%, are almost entirely the consequence of errors in measurement, and that the average tilt sensitivity of 2.35 in/rad should be used for both instruments.

Natural Period. The undamped natural period of the pendulum was measured by removing the damping magnets and counting swings with a stop watch. With both magnets removed, the damping of the system is so small that some 50 complete cycles can easily be counted. With the upper magnet alone removed, which can be done without removing or otherwise disturbing the pendulum, it is possible to count a dozen or so swings. The 10% damping for which the instrument is designed should change the natural period by the factor $1/\sqrt{1-(0.10)^2} = 1.005$, so that for most practical purposes no distinction needs to be made between the damped and the undamped periods.

Both of the instruments had the same period within the accuracy of the measurement, the value used in the calculations being 0.73 seconds. This is considered to be sufficiently close to the standard design value of 0.75 seconds for practical purposes.

The pendulum periods were measured for swings in various directions, and no significant variations were noted. The degree of dynamic symmetry attained in the present design is such that the vibrations remain in the plane in which they are initiated, with no evidence of coupling effects of various modes.

Damping. The damping of the pendulum was determined by measuring the decay of free vibrations. The pendulum was deflected by hand through the

maximum desired angle, and as it was released, it was given a slight push in a direction perpendicular to that in which it would normally fall. This procedure results in a smoked glass record having the form of an elliptical spiral, as shown in Figs. 6 and 7.

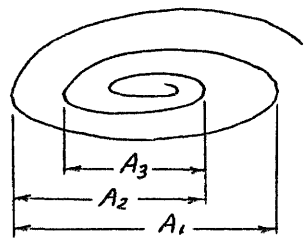


Fig. 6

From the ratios of successive double amplitudes the fraction of critical damping $n = \left(\frac{c}{c_c}\right)$ as previously defined may be calculated by the formula

$$n = \frac{1}{\pi} \log_e \left(\frac{A_n}{A_{n+1}}\right)$$

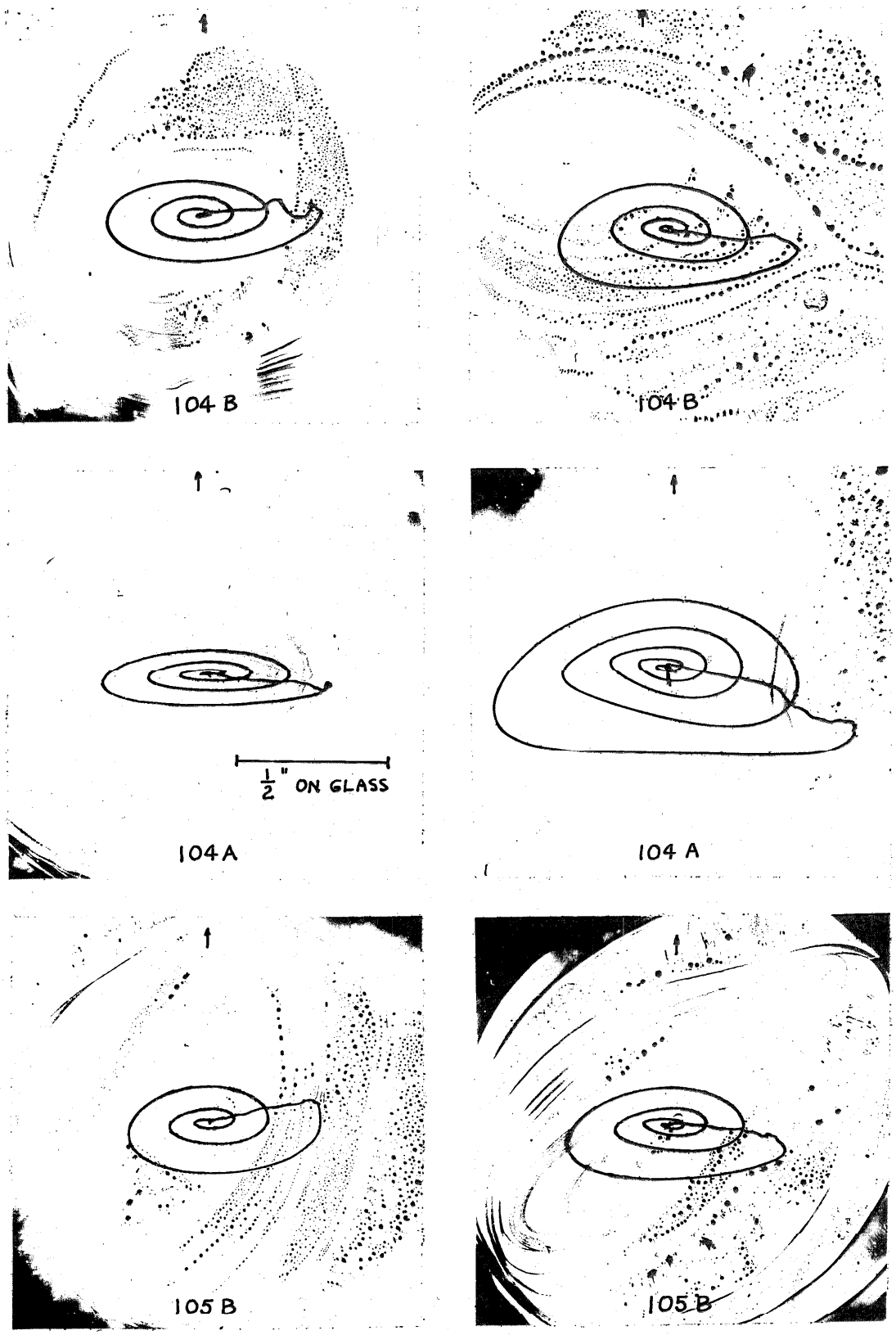
Values of n expressed in per cent for various amplitude ratios $\left(\frac{A_n}{A_{n+1}}\right)$ are given in Table II for the range of interest for the present device.

Table II - Damping Ratios

$\left(\frac{A_n}{A_{n+1}}\right)$	n, %
1.30	8.3
1.31	8.6
1.32	8.9
1.33	9.1
1.34	9.3
1.35	9.6
1.36	9.8
1.37	10.0
1.38	10.3
1.39	10.5
1.40	10.7
1.41	10.9
1.42	11.2
1.43	11.4
1.44	11.6

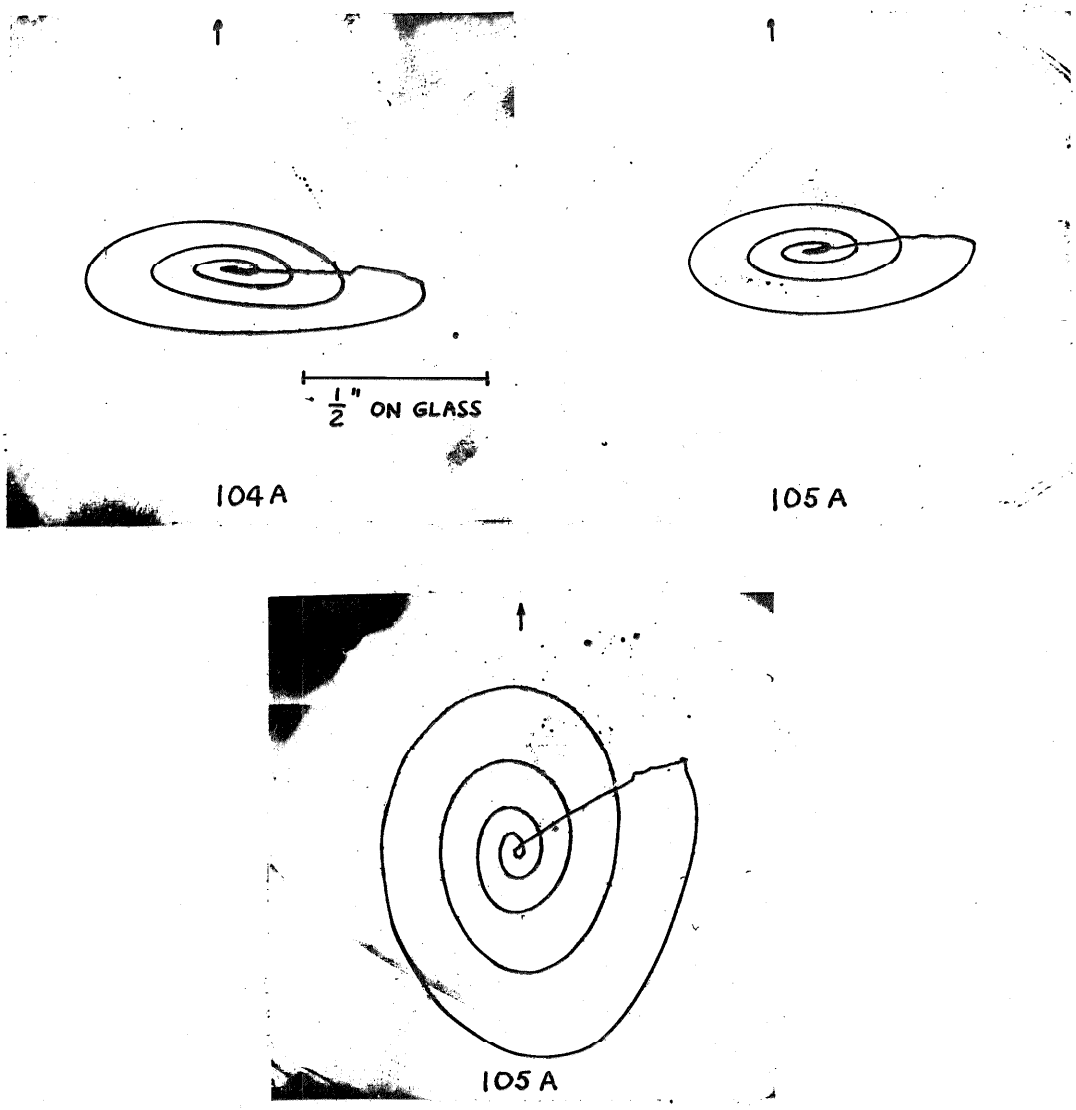
Trial adjustments of the damping magnet spacing were made until the per cent of critical damping was approximately 10% in the center of the scale. Photographic records of the smoked glasses obtained during the damping tests are shown in Figs. 7a and 7b. Those records marked B were made before the accelerometer monitored calibration tests, and those marked A were made after the calibration tests. From the records of Fig. 7 and the amplitude ratio data of Table II, the per cent of critical damping was determined in several tests for each instrument as a function of the amplitude of the motion at the beginning of the cycle. The results of these calculations, shown in Fig. 8, indicate that the damping is not a pure viscous resistance which is a constant independent of amplitude. Evidently an appreciable component of the damping is caused by the stylus friction, which is a dry, Coulomb type of damping for which the per cent of critical damping should increase as the amplitude decreases.

For the present tests, the stylus force was adjusted to be about 1-1/2 grams, as measured by a spring balance. This is believed to be somewhat higher than would be required to insure proper contact at all times between the stylus and the glass. Since the stylus assembly can be balanced on its knife edges by adjusting the knurled nut with the spring disconnected, vertical inertia forces should not disturb the stylus force. It is probable that if this stylus force were reduced to 1/2 - 3/4 grams, the variation of damping with amplitude would not be as marked as in the present tests. That this reduced force would be sufficient to prevent any vertical bounce is born out by tests of a previous model during a quarry blast. With a



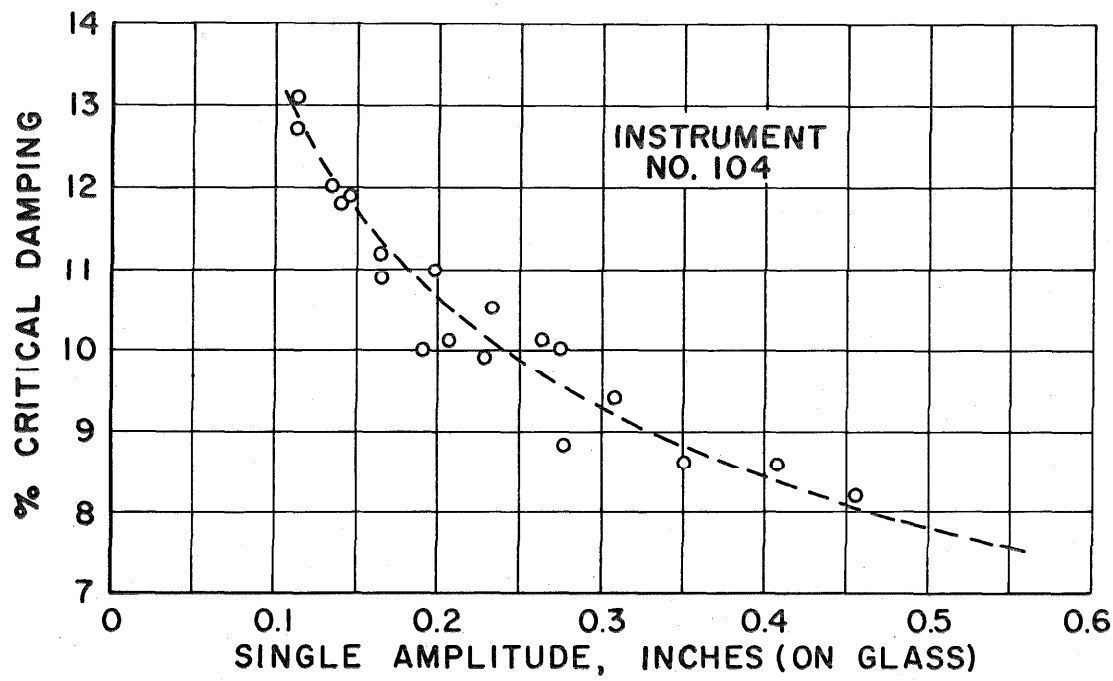
DAMPING TEST RECORDS

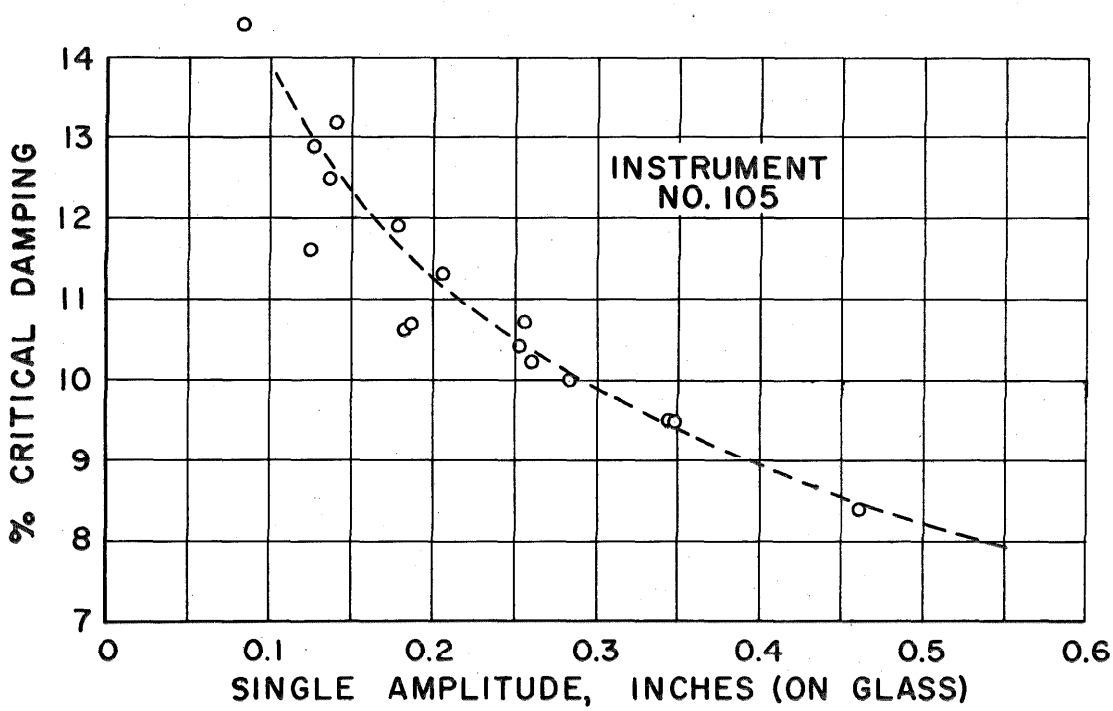
FIG. 7a



DAMPING TEST RECORDS

FIG. 7b





DAMPING TEST RESULTS

FIG. 8

stylus force of something less than 1 gram, the instrument was subjected to vertical accelerations of 0.18 g along with horizontal accelerations of 0.20 g with no evidence of bouncing.

For the present calibration tests, the curves of Fig. 8 were used as correction curves to adjust for the variation of damping with amplitude. The damping was read off the curve corresponding to the maximum amplitude found on the test runs of Fig. 5. It will be noted from the curves of Fig. 8 that the magnet adjustment has resulted in the desired 10% damping at about the midpoint of the scale. For other amplitudes, the final values of the response spectrum S_V were corrected by means of the relationship:

$$[S_V]_{10\%} = [S_V]_n \sqrt{\frac{n}{0.10}}$$

This square-root correction would be theoretically correct if the exciting function were a random function (ref. 1), and it should be a good approximation for earthquake-like excitations.

Calibration Results. The maximum displacements in the various directions as measured from the records of Fig. 5 are shown in Table III, along with the appropriate damping values from Fig. 8. The results of the final calculations of the maximum relative velocity response spectrum S_V for the various runs are shown in Table IV. All values have been corrected to the standard damping of 10%, and hence the S_V values of Table IV represent the response spectrum points corresponding to the period of 0.73 seconds and a damping of 10% of critical.

Table III. Calibration Test Runs

INSTRUMENT AND TEST NO.	MAXIMUM DISPLACEMENT INCHES ON SMOKED GLASS				PER CENT OF CRITICAL DAMPING	
	N	S	E	W	NS	EW
104-1	0.409	0.465	0.511	0.409	8.0	7.8
104-2	0.350	0.296	0.574	0.641	8.8	7.2
104-3	-	-	0.522	0.625	-	7.2
104-4	0.484	0.475	-	-	7.8	-
105-1	0.568	0.595	0.631	0.559	7.7	7.6
105-2	0.670	0.590	0.698	0.707	7.5	7.4
105-3	0.379	0.379	-	-	9.2	-
105-4	-	-	0.458	0.430	-	8.5

Table IV. Maximum Relative Velocity Response Spectrum Point, S_v

INSTRUMENT AND TEST NO.	S_v FT/SEC: T = 0.73 Sec., n = 0.10	
	NS	EW
104-1	0.666	0.725
104-2	0.525	0.871
104-3	-	0.849
104-4	0.684	-
105-1	0.834	0.879
105-2	0.926	0.970
105-3	0.580	-
105-4	-	0.673

Spectrum Analysis of the Acceleration Records. The response spectrum curves for the acceleration records of Fig. 4 were calculated using an electric analog response spectrum analyzer (refs. 4 and 5). In Figs. 9a, b, c the portions of the maximum relative velocity response spectrum curves of interest for the present tests are plotted. Three damping values of 5, 10, and 15% of critical damping are given for a period range of approximately 0.68 to 0.80 seconds, covering the range of response of the Wilmot instrument. Plotted on these same diagrams are the response spectrum points from Table IV, as measured by the Wilmot instrument. If there were no errors, these points should fall on the 10% damping line, and the magnitude of the departure from this line is a direct indication of the overall accuracy of the whole process of evaluating the response spectrum by the two methods. Part of the difference is of course a consequence of errors in the measured acceleration curves, and in the process of making the electric analog spectrum analysis.

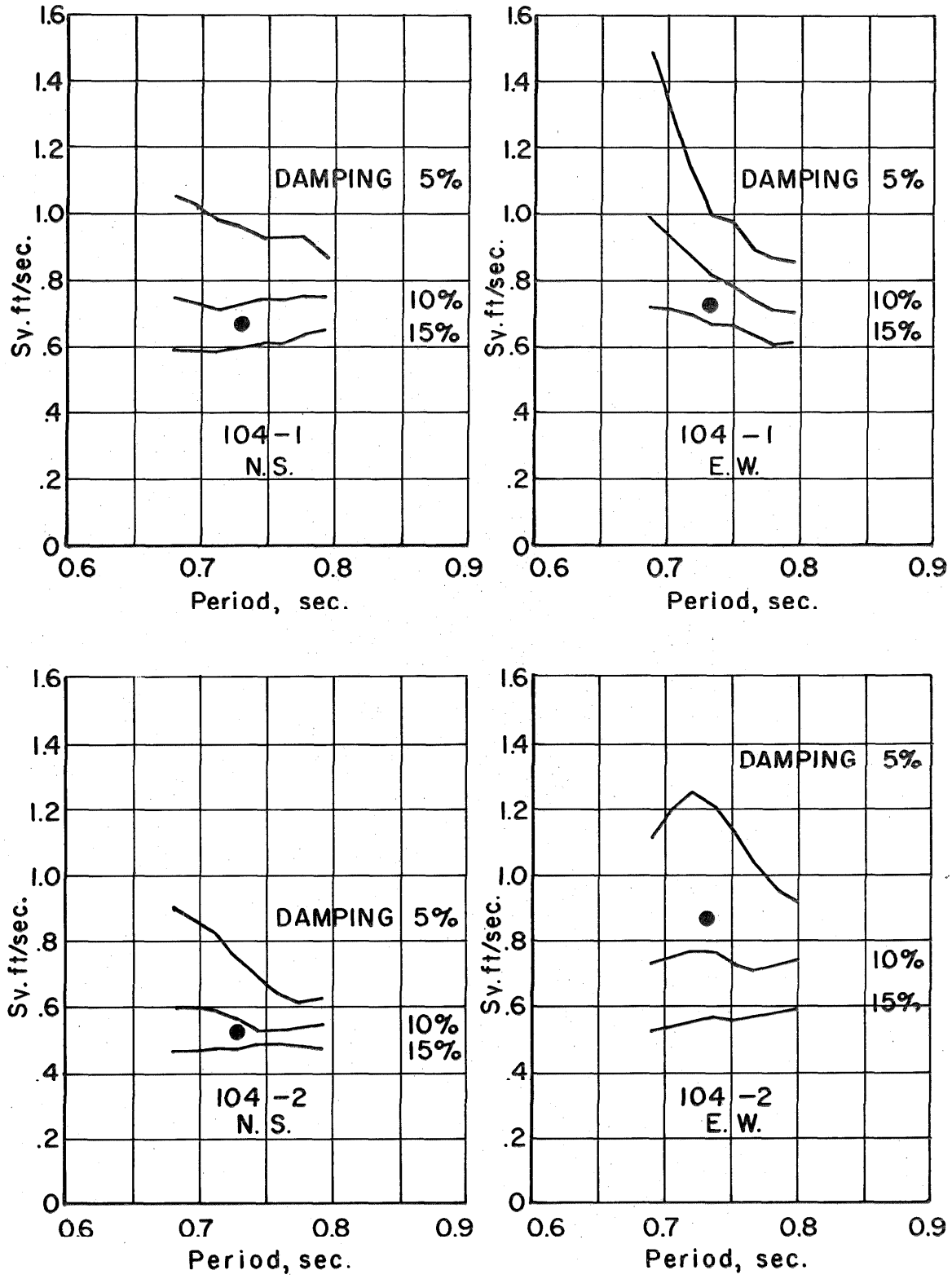


FIG. 9a RESPONSE SPECTRUM CHECK — WILMOT INSTRUMENT

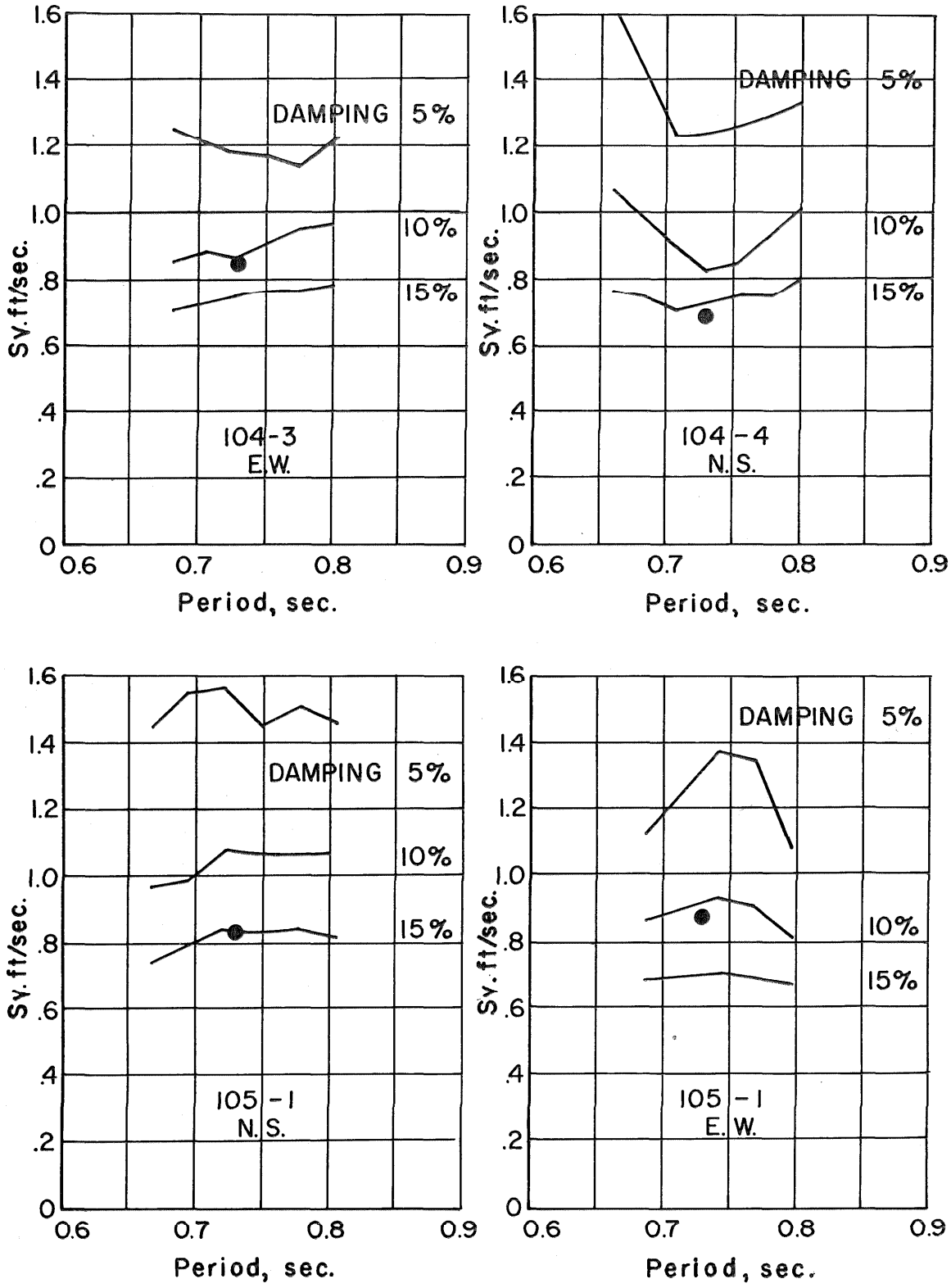


FIG. 9b RESPONSE SPECTRUM CHECK — WILMOT INSTRUMENT

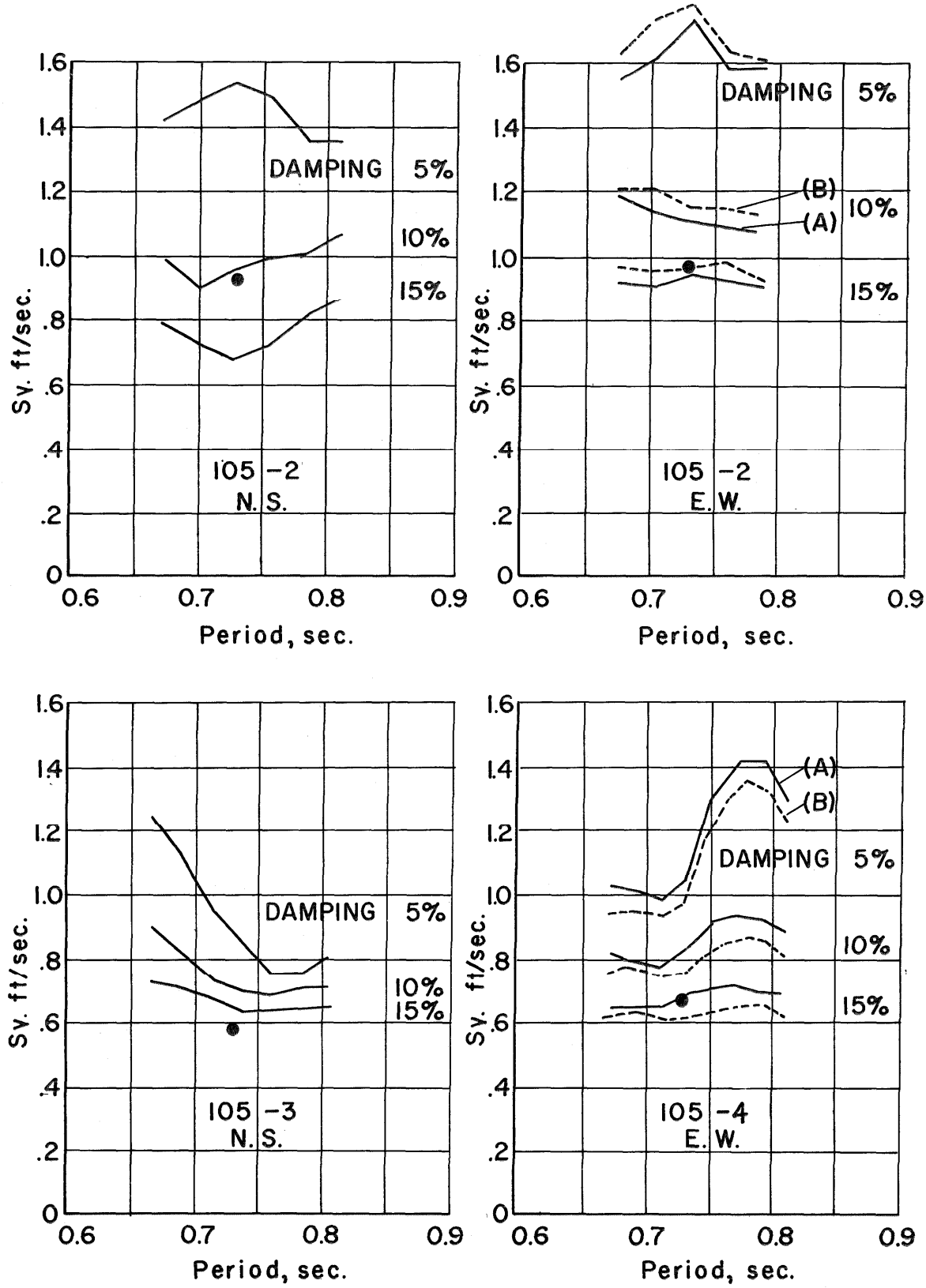


FIG. 9c RESPONSE SPECTRUM CHECK — WILMOT INSTRUMENT

To study the errors involved in the electric analog analysis, some duplicate runs were made. For test No. 105-2 EW of Fig. 4 and Fig. 9c, a duplicate film record was made on the plotting table for the function generator of the electric analog response spectrum analyzer, and the spectrum determination was repeated. The two sets of curves marked A and B show the comparison between these runs. For test No. 105-4 of Fig. 9c, new enlargements of the original accelerograms of Fig. 4 were prepared as well as new films for the function generator. The curves marked A and B for this test therefore show the accuracy to be expected for the whole process of producing the spectrum analysis from the original accelerogram. This overall accuracy of the spectrum analysis is seen to be of the order of 5 to 10% with the larger errors being associated with the small S_v values.

The percentage deviations between the two methods of determination of S_v as shown in Figs. 9 a, b, c are summarized in Table V.

Table V. Deviations in Spectrum Determinations, %

INSTRUMENT AND TEST NO.	PER CENT DIFFERENCE IN S_v BASED ON MEAN	
	NS	EW
104-1	9	12
104-2	9	13
104-3	-	2
104-4	20	-
105-1	26	4
105-2	4	15
105-3	20	-
105-4	-	16

There are some systematic trends evident from Figs. 9 a, b, c. For example, test no. 104-2, Fig. 9 a, is the only test for which the Wilmot instrument point lies above the response spectrum line. It is thus evident that the effective damping actually present in the Wilmot instrument is somewhat larger than that determined by the above methods. It would probably require many more tests, however, to establish a rational correction factor, and in view of other inaccuracies in the process a further damping correction is not believed to be feasible.

For each instrument tests were run with the pendulum motion essentially in one plane, and with a pendulum motion of about the same magnitude in all directions. In Fig. 5a, for example, test no. 104-1 has approximately equal displacements in the NS and the EW directions, while in test no. 104-4 the only significant motion is one the NS direction. A comparison of these tests should reveal whether the effects of coupling by the damping force, as discussed in connection with Fig. 2c above, are in fact appreciable for typical operating conditions. A comparison of all such tests shows no systematic differences in the two situations, and hence the conclusions of the simplified analysis which showed that the damping forces are small compared with the restoring forces are confirmed within the accuracy of measurement.

A comparison of the results obtained for the two different instruments tested shows no significant differences in their behavior. It appears that with the present design the usual manufacturing tolerances will produce instruments which are effectively identical.

The deviations indicated in Table V are consistent with the accuracies of measurement of the various steps of the process as discussed above. Considering the errors in measurement from the smoked glass plate as indicated by the tilt-sensitivity tests, the errors in damping determinations, and the accuracy of the response spectrum calculations, the agreement between the two methods could not be greater than that indicated in Fig. 9. Since the deviations of Fig. 9 are not to be attributed entirely to the Wilmot instrument, it is believed that it would be justified to describe the Wilmot instrument as having an accuracy of 10%. This accuracy is adequate for the job which the instrument is expected to do, and it is not felt that additional refinements in the design would be warranted.

Conclusions.

1. A direct comparison between the readings of the Wilmot instrument and the spectrum analysis of the base accelerations indicates that

   a) There is no significant difference in the behavior of the two instruments tested.

   b) The effects of damping coupling and torsional motions do not appreciably affect the results, within the overall accuracy to be expected.

   c) The accuracy of the measurements from the Wilmot Instrument is of the order of 10%. Approximately half of this error is a reading error associated with the size and nature of the record, and the other half is to be attributed mainly to uncertainties as to the effective damping present under actual conditions of use.

2. The design of the Wilmot instrument as tested is satisfactory for the anticipated use of the device as a supplement to the recording accelerographs of the U. S. Coast and Geodetic Survey, for the measurement of strong-motion earthquakes.

Acknowledgement. The development of the instrument and the construction of a number for installation has been made possible by a grant from the Engineering Science Division of the National Science Foundation, and special thanks are due this organization for their interest and cooperation. The present project is one part of a broader program of study of the local distribution effects of strong-motion earthquakes, sponsored by the National Science Foundation under the direction of Professor George W. Housner of the California Institute of Technology and the writer.

The original development work on the instrument was carried out by the U. S. Coast and Geodetic Survey in cooperation with the Earthquake Engineering Research Institute. Mr. William K. Cloud, Chief of the Seismological Field Survey of the U. S. Coast and Geodetic Survey was a most cooperative link between this work and the present project.

Much of the preliminary work on the determination of instrument characteristics was done by Mr. Howard C. Merchant, a National Science Foundation Fellow and graduate student in Mechanical Engineering at the California Institute of Technology. The final test work and the spectrum analysis of the base accelerations was the work of Mr. Wilfred D. Iwan, also a graduate student in Mechanical Engineering. Appreciation is expressed to both of these men for their many contributions to the project.

The final production design of the instrument was very ably carried out by Mr. Joe Wilmot, of the Wilmot Engraving and Instruments Company, who deserves special thanks for his careful and conscientious work.

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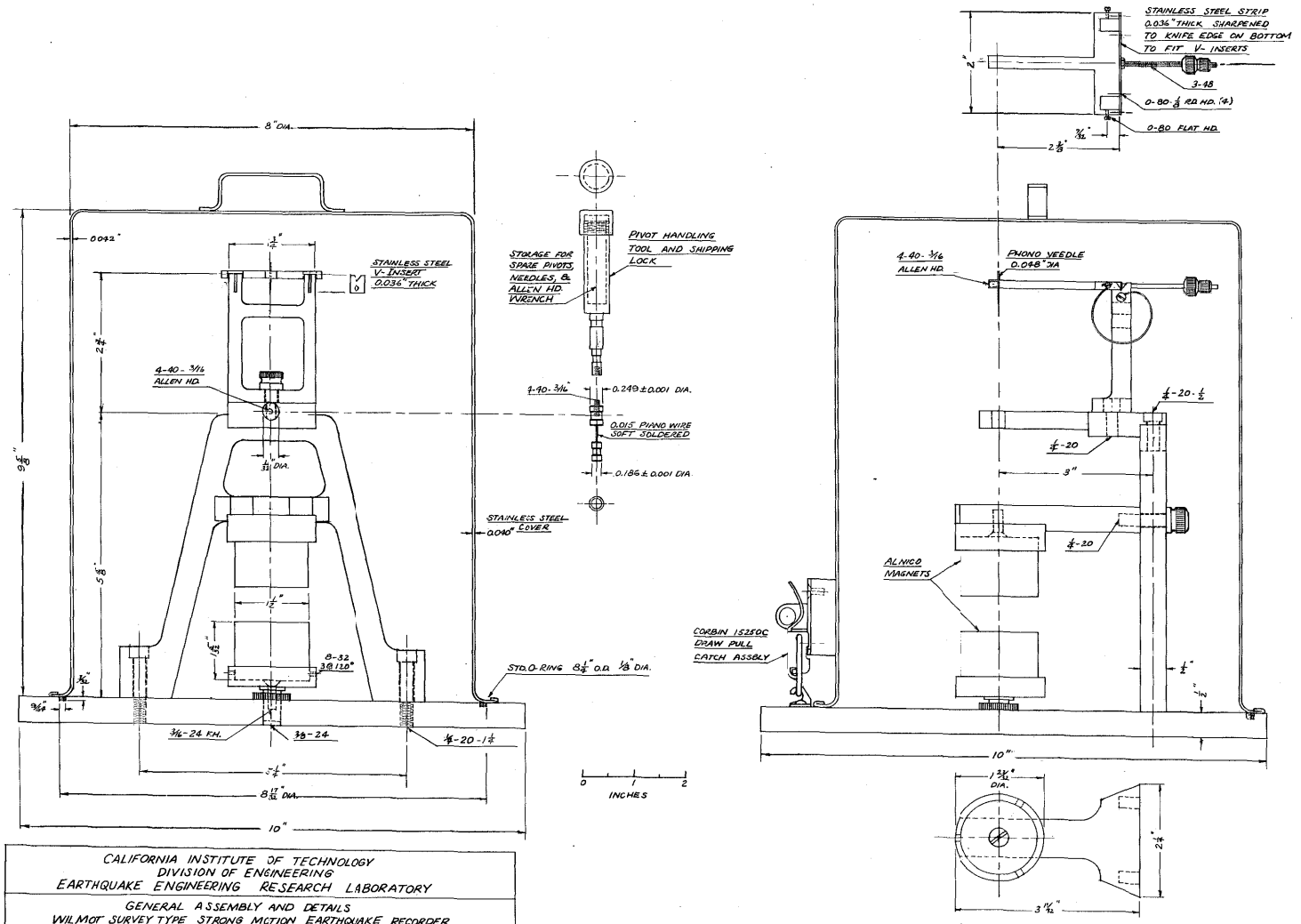
Appendix I

The following two figures include complete working drawings and assembly views of the final design of the Wilmot instrument as tested.



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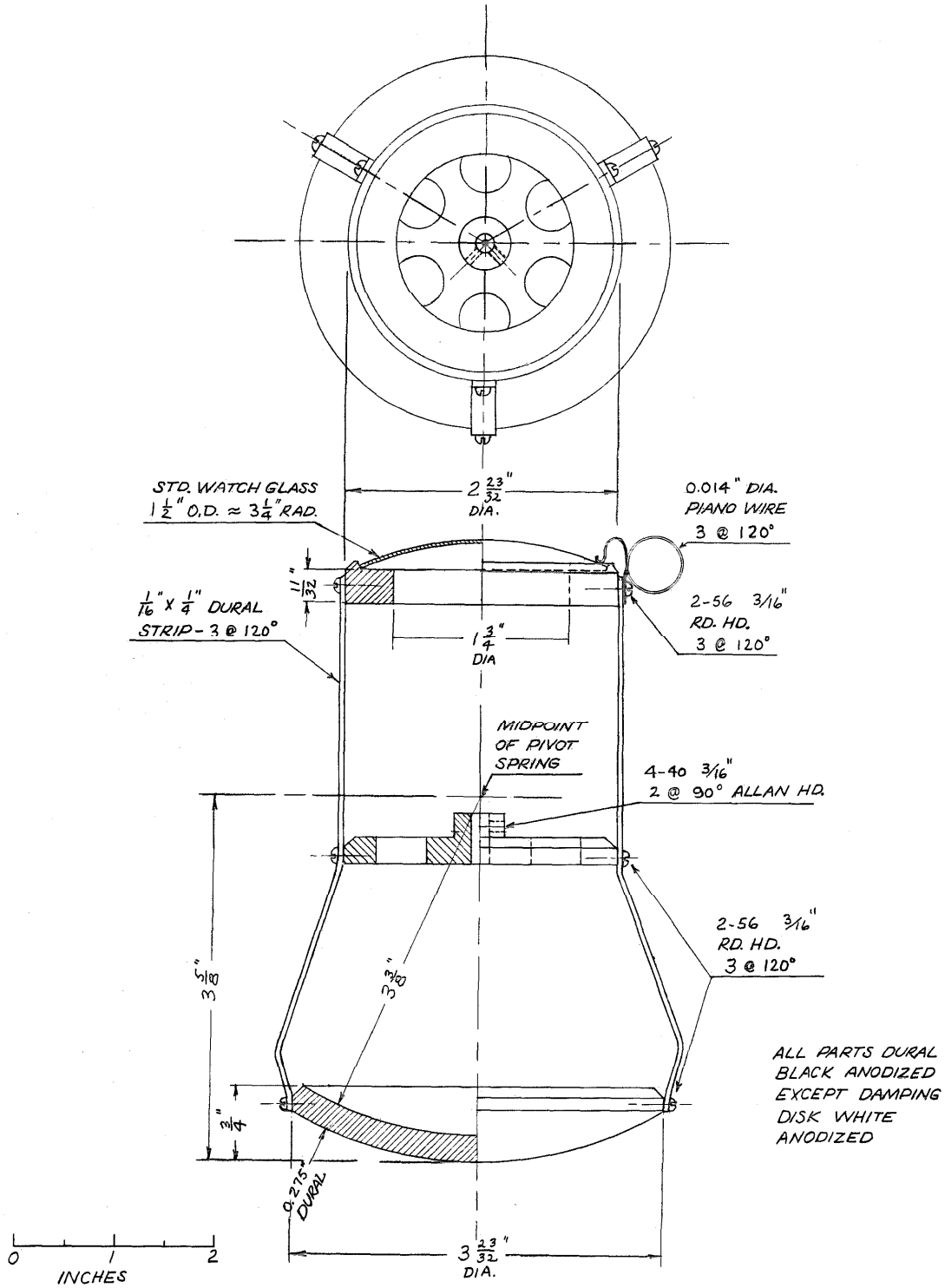
GENERAL ASSEMBLY AND DETAILS
WILMOT SURVEY TYPE STRONG MOTION EARTHQUAKE RECORDER

D.E.H.
8-3-58



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PENDULUM ASSEMBLY
WILMOT SURVEY TYPE STRONG MOTION EARTHQUAKE RECORDER

D.E.H.
8-9-56

Appendix II
Some General Instructions for the Installation and Operation of the Wilmot Instrument

The original design requirements for the simplified strong-motion earthquake recorder specified a device which would be relatively inexpensive, of the order of $100, and which would be sufficiently simple in operation so that it could be effectively installed and used by persons with no special training in the field. It is believed that the present instrument satisfactorily fulfills these requirements. The main body of the report contains many details concerning the measurement of instrument characteristics, the adjustment and measuring of damping, etc. The following remarks will include some miscellaneous suggestions on the use of the instrument.

Assembly and Installation. As packed for shipment the pendulum suspension pivot is replaced by the end of the pivot handling tool, which thus serves as a shipping clamp. The large end of this tool unscrews, and contained inside will be found two suspension pivots (one spare), two scriber needles (one spare), and an Allen head wrench for the suspension pivot clamping screws. With the suspension pivot finally in place, this tool can be stored in the clamp provided at the back of the main support bracket.

The instrument itself should be mounted if possible on a concrete basement floor in a reasonably clean and dry location. Some thought should be given to choosing a location, such as in a corner, in which the instrument is likely to be safe from interference or accidental disturbance. Since the scriber assembly is adjustable, the instrument does not have to be accurately leveled, although the mounting surface should be reasonably level. The two mounting bolts supplied with the instrument should be installed in holes drilled in the concrete supporting surface.

In placing the cover on the instrument care should be taken not to strike against the top scriber assembly.

Smoking the Glass Plate. The glass record plate is a standard 65 mm size watch glass or equivalent such as can be obtained from any scientific equipment supply house.

For smoking the glass plates most any candle should be suitable. By moving the lighted candle back and forth under the glass plate about an inch below it, it will be found that a uniform layer of soot can be deposited. This layer should not be thickly built up - a thin, almost translucent layer will be most suitable for making the record. The glass should be clean and dry before smoking. As an alternate to the use of a candle, it will be found that a small piece of "camphor ice" about the size of a pea, will give a thick, dense cloud of soot when lighted. Small blocks of such camphor can be obtained in any drug store.

To preserve the record, the whole plate should be dipped into a thin, clear, lacquer, and the excess lacquer should be drained off. When thoroughly dry, the plate will then withstand any reasonable amount of handling. The plate in this form can be used as a negative in a photographic enlarger, and in this way photographic reproductions of the record can easily be made. Typical damping and calibration records should be lacquered and preserved for future reference.