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# SEISMOGRAPH CALIBRATIONS AT MUNDARING AND KALGOORLIE,

## WESTERN AUSTRALIA 1965 - 1966

*by*

*P.J. GREGSON*

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# CONTENTS



## ILLUSTRATIONS

## SUMMARY

Adjustments were made to the Kalgoorlie seismograph in 1965 and 1966 to improve its capability in the determination of the directions of local seismic events, and for routine teleseismic data production.

The seismograph was calibrated when necessary and three methods were tried: the Willmore Bridge method, comparison of recordings at Mundaring and Kalgoorlie, and an external coil method. Only the first method proved satisfactory, but the third should be developed for use on Willmore seismometers.

1967/46

## 1. INTRODUCTION

Seismographs continued in operation at Mundaring (MUN) and Kalgoorlie Airport (KLG) during 1965 and 1966. At Mundaring these consisted of a World-Wide Standard Seismograph (W.W.S.S.) installed in June 1962 and a Benimore vertical component installed in September 1962 (McGregor, 1966). A three-component seismograph was operated at Kalgoorlie. The instruments, installed in November 1964 (Everinghan, 1965), were mainly Benioff equipment (ex-Mundaring) with a Willmore vertical seismometer. Appendix 3 lists the details of the short-period seismographs in operation.

Absolute calibration curves were needed for the MUN Benimore vertical and the KLG vertical for determining magnitudes and reporting amplitudes in millimicrons to the USCGS. It was necessary to obtain at least relative curves for the KLG horizontals to determine the directions of local events occurring in the Kalgoorlie area. Ideally the two curves should be matched at their short-period end.

During the year, several adjustments and modifications to the KLG unit were required, after which it was necessary in some cases to recalibrate the seismograph. Any further adjustments will be shown in the annual report of the Mundaring Geophysical Observatory.

Three methods of calibration were tried: using a Willmore Bridge, using an external coil, and by comparison between MUN and KLG recordings of seismic events. The calibration curve of the W.W.S.S. is well established and was used as a check on each method.

## 2. ADJUSTMENTS, KLG

Adjustments to the Kalgoorlie seismograph are listed in Appendix 1. Where necessary, reasons for the adjustments are given below.

### Benioff horizontals

Because most of the local events recorded at Kalgoorlie are from an easterly direction, the two horizontal seismometers were rotated through 45° in January 1965 so that a better determination of their direction could be obtained. The directions of ground movement for an upward movement on the seismograms are given in Appendix 4.

The test pulse circuit (Everingham, 1965) was disconnected in January 1965 as it was found that both horizontal seismometers reacted on each other through the test coils. It was found later that a voltage-dividing resistor in the test pulse box formed a permanent closed circuit through the seismometer test coils. The circuit was modified and reconnected on 30th March 1966.

Prior to August 1965, a 50-Hz disturbance on the NW component when using the Willmore Bridge prevented accurate matching of the two horizontal components. The 50-Hz disturbance disappeared when a stray earth connection in the galvanometer lead of the NW control panel was found and removed. With the resulting higher accuracy of the bridge it was found that the two components were not as closely matched as was thought in March. Attempts to match them failed because of faulty 'free period' switches. When these were shorted out the two components were matched easily by adjusting the seismometer and galvanometer damping resistors.

During the calibration tests on 13th August 1965 a fault developed in the optical system of the SW galvanometer. The recording spot kept drifting out of position at right angles to the trace displacement. At first this drift caused the spot to disappear in about 15 minutes, but gradually the effect lengthened to several days. To determine whether it was due to the time-mark mirror warping or the galvanometer mirror tilting, the two horizontal galvanometers were interchanged with respect to the recording drums and time-mark mirrors, on 19th August 1965 (refer to Appendix 4 for directions of movement). Continued drift indicated that the fault was in the SW galvanometer. Drift after September 1965 became very slow and it eventually stopped.

At the end of October 1965, the NW component lost its sensitivity. The fault disappeared when the damping resistors were replaced during November. However, the fault recurred during December. A further examination in March 1966 revealed that the lead between the input plug on the rear of the recorder and the 'galvanometer control panel' was faulty and was shorting the seismometer. When replacing the damping resistors in November 1965, the short must have been disturbed by lifting the recorder lid. Subsequent activity during record changes caused the lead to re-short.

Attempts to locate the cause of a long-period (half-minute) drift seen on the NW component since installation failed except to show that it was located in the No. 3 control box. When the damping resistors were replaced in November 1965 the drift disappeared.

Early in July 1966 the gain of the SW component increased by approximately 25% as indicated by the daily test pulse. The attenuator was examined and found to be inconsistent when switching from step to step and back again. To eliminate any further changes a simple fixed attenuator was constructed for both horizontal components.

The final circuit diagrams for all components are shown in Plate 7.

# 3. CALIBRATIONS

## Methods

The following methods were examined and used to determine calibration curves and absolute magnification.

Willmore Bridge method. This method is described by Willmore (1959); the practical method is outlined in Appendix 2 where a list of symbols is given. The results were adjusted for variations in $R_B$ with different frequencies and also for the effect of the ratio resistor $R_R$. Correction for the latter was made by the rule of thumb given by Willmore (p. 114).

External coil method. This method was intended to give a relative comparison between the Benioff seismometers and, by using the W.W.S.S. vertical as a standard, to give their absolute magnification. A magnet was attached to the mass limit nut and position indicator. A coil (resistance 400 ohms) was placed over the top of the magnet and a known voltage applied at varying frequencies. It was thought that the ratio of the resulting deflections for two seismometers at any frequency would be equal to the ratio of the magnifications. However, after many tests this method proved unsatisfactory. Different results were obtained depending on which direction the external magnet was attached to the mass limit nut. Also it was found that for the MUN Benimore and KLG horizontals the seismometers reacted to a signal through the external coil even without the magnet attached. Further, the magnifications calculated for the KLG horizontals, by comparison of external coil deflections with MUN W.W.S.S. vertical deflections, were too low by as much as 75%. None of these features was evident on the W.W.S.S. vertical. All four Benioff seismometers tested gave distorted curves, the values being too low at the short-period end and too high at the long-period end. The distorted curves were probably due to incorrect matching between the external coil and the output of the function generator even though several resistances were tried in series with the external coil.

Record comparisons. The comparisons between the recordings of events at Kalgoorlie and Mundaring gave an estimate of the relative magnifications for the initial period of recordings at Kalgoorlie. It was subsequently noted that large differences occurred between amplitude ratios for different earthquakes presumably owing to nodal zones. Figures obtained from such comparisons can therefore only be used as a rough guide.

## Results

Appendix 5 and Plates 1 to 5 show the results of the Willmore Bridge calibrations.

MUN W.W.S.S. vertical. The Willmore Bridge was used to calibrate the vertical component of the W.W.S.S. The curve agrees with the Standard curve given by the USCGS. The absolute value was checked on 21st October 1965 and gave a value of 26,000 at c/s. The difference from the Standard absolute values (25,000 at 1 c/s) is no more than is expected with different calibration methods.

MUN Benimore vertical. The external coil method proved unsatisfactory for reasons stated above.

The seismograph was calibrated using the Willmore Bridge in August 1965. The magnification was 20,000 at 1 c/s. The curve continued to rise for shorter periods reaching 167,000 at a period of 0.2 second.

From 21st March to 21st August 1966 a different galvanometer was used having the same characteristics as the original galvanometer but being 30% more sensitive for periods 0.2 to 4.0 seconds.

KLG Willioff vertical. In January 1965 the Willmore Bridge was used but the results were unsatisfactory. A balance could not be obtained at the shorter periods. Also the ratio of deflections for main and substitution input drive did not show a minimum near the free period of the seismometer. By comparison with the Mundaring seismograms the magnification was between 1/3 and 1/2 of the W.W.S.S. vertical in the 0.8 to 1.0 second range.

The Willmore Bridge was used successfully in March 1965 and as a check in August 1965. Similar curves were obtained on both occasions except that the second was slightly higher at the shorter periods (below 0.6 second). A mean curve (Plate 2) was adopted from 26th January 1965 to 17th March 1966. The Willmore Bridge was used for a further calibration on 1st April 1966 to determine the increased sensitivity resulting from adjustments in March (see Plate 2).

KLG Benioff horizontals. In January 1965 the use of the bridge was hampered by a 50-Hz disturbance.

The external coil was used to give magnification curves. This method later proved to be unreliable, but relative magnifications for the seismographs are indicated by relative deflections, viz: E-W/N-S = 2.3.

Comparisons of suitable earthquakes at KLG and MUN showed the following approximate relations:

N-S KLG/N-S MUN = 0.35

E-W KLG/E-W MUN = 0.5

Hence, E-W KLG/N-S KLG = 1.5

Because the magnification of the W.W.S.S. at Mundaring is 25,000 at 1 c/s, the above relations indicate that the magnifications until 25th January were approximately:

N-S 9,000 at 1 c/s

E-W 13,000 at 1 c/s

Accurate absolute magnifications cannot be given because of the wide range shown in the above ratios. The values shown above were not used for determinations of directions.

A satisfactory calibration was achieved with the Willmore Bridge in March 1965 for the SW seismograph but failed for the NW owing to a 50-Hz disturbance. The external coil was used to compare the curve shapes, which were found to agree. However, the accuracy of the comparisons was limited by the small deflections obtained.

Further calibrations were made in August 1965 to determine more accurately the absolute magnifications of the horizontal components. Both seismographs were calibrated on 10th August after eliminating the earth in the NW galvanometer lead referred to in Chapter 2. The magnification curve for the SW seismograph corresponded to that measured in March after adjustments and it is therefore assumed that these curves apply for the period 15th March to 13th August 1965.

Further calibrations were made following adjustments on 13th August 1965, 10th November 1965, 17th March 1966, and 27th July 1966. The resulting curves and periods over which they are valid are shown in Plates 3 to 5.

To determine the directions of local events it is necessary to take into account the difference in magnification of the two horizontal components. The magnification ratio is the same over the range of period 0.1 to 0.4 second. The P-phases from local events fall into this range. The ratios used for the various time periods are given in Appendix 4.

## 4. RECOMMENDATIONS

Calibrations are required after any adjustments (other than direct attenuator adjustments) that will alter the shape or level of the calibration curves. For the horizontal curves it is essential that the ratio of their magnifications be accurately known for periods less than 0.6 second in order that the directions of local events can be determined with reasonable accuracy. An error of 2% in the magnification ratio can give up to half-a-degree error in the direction of an event. For the vertical curve the magnification need only be known to 10% to give an error of less than 0.05 in magnitude determinations.

It is necessary to have a low-frequency function generator readily available at all times, for calibrations at field stations, when high accuracy is to be maintained in determining directions of local events. The Willmore Bridge required at present could be eliminated by attaching electromagnetic calibrators to all Benioff seismometers. Such calibrators are used in the W.W.S.S. seismometers (Geotechnical Corporation, 1961) and are designed to fit in the seismometers in place of one of the mass locking bolts. Calibrations could then be simply made with the use of a function generator and the electromagnetic calibrator, as described in the Geotechnical Corporation manual. In addition, a test pulse could be applied each day by the operator, which would immediately indicate any changes in the magnification. An external coil having the same functions as the Benioff electromagnetic calibrators should be designed so that it could be attached to the Willmore seismometers.

## 5. REFERENCES


EVERINGHAM, I.B. 1965 Installation of a seismograph at Kalgoorlie, WA 1964. Bur. Min. Resour. Aust. Rec. 1965/63.

GEOTECHNICAL CORPORATION 1961 Operation and maintenance manual, World-Wide Seismograph System, Model 10700.

McGREGOR, P.M. 1966 Mundaring Geophysical Observatory, annual report 1962. Bur. Min. Resour. Aust. Rec. 1966/35.

WILLMORE, P.L. 1959 The application of the Maxwell impedance bridge to the calibration of electromagnetic seismographs. Bull. Seism. Soc. Amer. Vol. 49, pp. 99-114.

## APPENDIX 1

### Log of adjustments and calibrations to KLG seismograph

| Date | Component | Action |
|---|---|---|
| 1965 | | |
| January | | |
| 25 | Z (88187) | F.P. measurement (0.70); coil leads broken during adjustment. |
| 26 | N, E | Seismometers turned through 45° (to become NE-SW and NW-SE). |
| | Z (88188) | Replacement geophone; F.P. (0.70). |
| | SW, NW | Reset attenuator (increased gain by 1/3). |
| | Z, SW, NW | Disconnected test pulse circuit. Calibration tests. |
| March | | |
| 11 | Z (88188) | F.P. measurement (0.70) Calibration tests. |
| 15 | Z (88188) | Galvanometer leads reversed so that movement up the seismogram corresponds to an upward ground movement. |
| | NE | Adjustment to galvanometer damping to match horizontal components for short-period phases (as a result of January calibration). |
| | SW, NW | Reset attenuators (increased gain by 1/3). Calibrations. |
| August | | |
| 12 | NW | Removed earth from galvanometer lead in control box. |
| | SW, NW, Z | Shorted out F.P. switches as found to be faulty. |
| 13 | SW, NW | Calibration tests. |
| 19 | SW, NW | Interchanged galvanometers with respect to recording drums. |

| | | |
|---|---|---|
| 1965<br>November | | |
| 10 | SW, NW | All damping resistances measured and the potentiometers replaced by variable fixed resistors of 50 ohms set at 15 ohms. |
| | NW | The galvanometer fixed damping resistance (50 ohms) was replaced |
| | NW | Reversed galvanometer leads (accidently). |
| | NW, SW | Calibration tests |
| 1966 | | |
| March | | |
| 16 | Z, SW, NW | F.P. measurement. |
| | SW, NW | Seismometer turned 2° clockwise after checking their orientations. |
| | SW, NW | Replaced galvanometer and seismometer damping potentiometer with fixed resistors of 22 ohms. Reset attenuators to match both seismographs as near as possible. |
| 17 | Z | Gain increased by increasing galvanometer damping resistor from 25 ohms to 290 ohms. |
| | SW, NW | Interchanged galvanometers, with respect to recording drums, to their original positions as prior to August 19th 1965. |
| | Z, SW, NW | Calibrations |
| 30 | NW | Seismometer leads connected directly to the terminal board of No. 3 control panel, thus eliminating faulty lead between recorder plug and terminal board. Galvo leads reversed (accidently). |
| | SW, NW | Reconnected modified test pulse circuit. |
| | NW | Decreased gain (by 1/3) so that test pulse lengths of both horizontals almost equal. |
| April | | |
| 1 | Z, SW, NW | Calibrations |

| | | |
|---|---|---|
| 1966 July | | |
| 27 | SW, NW | Replaced all resistors, including the attenuators, in circuits of both seismographs with fixed resistors. Both circuits were made identical as follows: |
| | | line set 91 ohms |
| | | seismo damp 33 ohms |
| | | galvo damp 33 ohms |
| | | "T attenuator" |
| | | seismo side 0 ohms |
| | | galvo side 200 ohms |
| | | parallel to seismo and galvo 33 ohms |
| | SW, NW | Calibrations |

## APPENDIX 2

### Willmore Bridge Method

#### Symbols

| | | |
|---|---|---|
| $K$ | = | Seismometer flux linkage |
| $R_C$, $R_B$, $R_R$, $C_B$ | = | See circuit diagram (Plate 6) |
| $f_M$ | = | Resonant frequency of seismometer |
| $f$ | = | Frequency of drive voltage |
| $\theta_2$ | = | Trace deflection in centimetres (half total deflection) due to drive voltage |
| $\theta_4$ | = | Trace deflection in centimetres due to substitution volts |
| $G^2$ | = | $(\theta_4 / \theta_2)^2 / (f - f_M^2 / f)^2$ |
| $M$ | = | Mass of moving portion of seismometer (grams) |
| $A$ | = | Simultated ground acceleration |
| $Ed$ | = | Drive voltage |

#### Method

This appendix briefly describes the practical work and calculations for using the Willmore Bridge to calibrate the seismographs at Mundaring and Kalgoorlie. Willmore (1959) describes the method and the reader is assumed to be familiar with his paper. In addition it is advisable to refer to the Willmore Seismograph Calibrating Bridge Handbook, which lists precautions to take to protect the instruments.

#### Setting-up

The circuit is set up as shown in Plate 6. It is most convenient to set up the bridge and function generator as near as possible to the recording drum.

#### Calibration

The seismometer mass is clamped and the bridge balanced for acceleration input over the desired range of frequencies (10 to 0.25 c/s). The best way to obtain a balance is first to obtain a minimum deflection by adjusting $R_R$, then successively adjusting $R_B$ and $C_C$. When the final balance is being made apply the maximum drive voltage by using the 'drive amplitude' control of the amplifier.

Before unclamping the seismometer the 'drive voltage' is set at a convenient value and measured at 1 c/s. For Benioff seismometers with a magnification of 25,000 at 1 c/s a drive voltage of 0.7 volt will give a deflection $2\theta_2$ of approximately 6 cm. For Willmore seismometers (mass 4.3 kg) with a magnification of 20,000 at 1 c/s, a drive voltage of 0.4 volt will give a deflection $2\theta_2$ of approximately 4 cm.

The seismometer is then unclamped and the galvanometer deflection $\theta_2$ for the 'main input' drive is observed at various drive frequencies ('acceleration input'). The shape of the seismometer response curve is found from these observations. Response is proportional to $\theta_2 . f^2$.

The drive is then switched to 'substitution input' and with the seismometer unclamped the galvanometer deflections ($\theta_4$) are measured over the required range of frequencies.

Calculations

It is convenient to make calculations in the following order using the computation form shown on Page 18.

(a) Plot f against $\theta_4/\theta_2$ on semi-logarithmic paper (f on the logaritchmic scale). The minimum value of f on the curve obtained is the seismometer resonant frequency, $f_M$ (see below).

(b) Plot $(f - f_M^2 / f)^2$ against $(\theta_4 / \theta_2)^2$. The slope of the resulting straight line $(\theta_4 / \theta_2) / (f - f_M^2 /f)^2$ is equal to $G^2$.

(c) Calculate $K^2$

$$K^2 = M \cdot 2\pi \cdot R_R (R_B + R_C) \times 10^9 / G (R_R + 10{,}000)$$

(d) Calculate A

$$A = K.Ed. 10^{-1} / M(R_B + R_c)$$

(e) Calculate magnification for all frequencies

$$MAG = (2\pi f)^2 \theta_2 / A$$

Corrections are made for the effect of the ratio resistor $R_R$ in series with the seismometer load when the bridge is balanced, but removed when the deflections $\theta_2$ are measured. The maximum effect of this is $R_R / (R_C + R_R)$, which applies for frequencies remote from the resonant frequency; the effect is zero at the resonant frequency. Correction is made according to Willmore (1959, p. 114): "As rule of thumb we made the transition between these conditions by applying the full correction at frequencies outside the limits of half and twice the resonant frequency and by applying half the correction at frequencies of about two thirds and one and one half times resonance". Correction is also made where necessary for the effect of changing the bridge resistance $R_B$ for balance conditions at various frequencies, i.e. for changing the drive to the seismometer. The correction is to multiply the magnification by a factor $R^1{}_B / R_B$ where $R^1{}_B$ is the bridge resistance when balanced at the given frequency and $R_B$ at the standard frequency (1 c/s) at which Ed was measured.

Seismometer resonant frequency

During calibration the seismometer resonant frequency can be determined directly by adjusting the frequency of the function generator so that a minimum deflection $Q_4$ is obtained when using the substitution input. This frequency is the seismometer resonant frequency. If this method is used then there is no need for step (a) in the calculation.

The circuit can also be used for accurately adjusting the seismometer resonant frequency to a desired value. The function generator is set at the required frequency and the seismometer (resonant frequency) adjusted until the deflection $Q_4$ is a minimum on substitution input.

# APPENDIX 3

## Details of MUN and KLG short-period seismographs

| Instrument | MUN W.W.S.S. | MUN Benimore-Z | KLG Willioff-Z | KLG Benioff-Horiz. (2) |
|---|---|---|---|---|
| Seismometer | W.W.S.S. | Benioff | Willmore | Benioff |
| Galvanometer | W.W.S.S. | Willmore | Benioff | Benioff |
| Recorder | W.W.S.S. | Willmore | Benioff | Benioff |
| Seismo F.P. | 1.0 s | 1.0 s | 0.7 s | 1.0 s |
| Galvo. F.P. | 1.75s | 0.04s | 0.25s | 0.25s |

# APPENDIX 4

## Control settings and characteristics

| | Atten. | Galvo Damp. | Seismometer Damp. | Seismometer F.P. | Ground∅ Motion | Ratio of KLG Horiz. SW/NW |
|---|---|---|---|---|---|---|
| MUNDARING | | | | | | |
| W.W.S.S.-Z | 12 | | | 1.00 | Up | |
| Benimore Z | NIL | | | 1.00 | Down | |
| KALGOORLIE | | | | | | |
| Willioff-Z | | | | | | |
| from | | | | | | |
| 7/11/64 | 0 | 10+ | Open | 0.70 | Down | |
| 15/3/65 | 0 | 10+ | Open | 0.70 | Up | |
| 13/8/65 | 0 | 10+ | Open | 0.66 | Up | |
| 17/3/66 | 0 | 290ohms | Open | 0.67 | Up | |
| Horizontals | | | | | | |
| Drum No. 2 from | | | | | | |
| 7/11/64 | 6 | 10 | 10+ | 1.06 | S | |
| 26/1/65 | 4 | 10 | 10+ | 0.98 | SW | |
| 15/3/65 | 2 | 10 | 10+ | 0.98 | SW | = 1.20 |
| 13/8/65 | 2⁻ | 10 | 10+ | 0.98 | SW | = 1.06 |
| 19/8/65* | -2 | 10 | 10+ | 0.99 | NW | = 1.06 |
| 10/11/65 | -2 | - | - | - | SE | = 1.02 |
| 17/3/66 | 0 | 22 ohms | 22 ohms | 1.00 | SW | - |
| 1/4/66 | 2 | 22 ohms | 22 ohms | 1.00 | SW | 1.20 |
| 27/8/66 | fixed | 33 ohms | 33 ohms | 1.00 | SW | 0.80 |

| | Atten. | Galvo. Damp. | Seismometer Damp. | Seismometer F.P. | Ground ∅ Motion | Ratio of KLG Horiz. SW/NW |
|---|---|---|---|---|---|---|
| Drum No. 3 from | | | | | | |
| 7/11/64 | 10 | 10 | 10 | 1.04 | W | |
| 26/1/65 | 8 | 10 | 10 | 0.99 | NW | |
| 15/3/65 | 6 | 10 | 10 | 0.99 | NW | = 1.20 |
| 13/8/65 | -2 | 10 | 10 | 0.99 | NW | = 1.06 |
| 19/8/65* | 2⁻ | 10 | 10 | 0.98 | SW | = 1.06 |
| 10/11/65 | 10 | - | - | - | SW | = 1.02 |
| 17/3/66 | 0 | 22 ohms | 22 ohms | 1.0 | SE | - |
| 1/4/66 | 0 | 22 ohms | 22 ohms | 1.0 | NW | = 1.20 |
| 27/8/66 | fixed | 33 ohms | 33 ohms | 1.0 | NW | = 0.80 |

* The horizontal seismographs were interchanged with repect to recording drums on 19th August 1965.

∅ Ground Motion for Up on Seismogram.

APPENDIX 5 (1)

Summary of calibrations

| STATION COMPONENT | | KALGOORLIE SW Att = 2 15 Mar. 65 | SW Att = 2 10 Aug. 65 | NW Att = 6 10 Aug. 65 | SW Att = 2 13 Aug. 65 | NW Att = 2 13 Aug. 65 | SW Att = 2 10 Nov. 65 | NW Att = 10 10 Nov. 65 | SW ATT= 2 31 Mar. 66 | NW ATT= 0 31 Mar. 66 |
|---|---|---|---|---|---|---|---|---|---|---|
| PERIOD (s) | FREQUENCY (c/s) | | | | | | | | | |
| 4.0 | 0.25 | 200 | 190 | 230 | 280 | 260 | 270 | 160 | 520 | 500 |
| 2.0 | 0.50 | 1440 | 1460 | 1540 | 2010 | 1750 | 1910 | 1190 | 3770 | 4680 |
| 1.5 | 0.67 | 3040 | 3190 | 3290 | 3870 | 3520 | 3790 | 2580 | | |
| 1.33 | 0.75 | | | | | | | | | |
| 1.0 | 1.0 | 8350 | 8900 | 8760 | 9210 | 8780 | 9660 | 7320 | 20990 | 19500 |
| 0.8 | 1.25 | 12930 | 14260 | 13660 | 13550 | 13430 | 14450 | 12010 | 30770 | 27590 |
| 0.75 | 1.33 | | | | | | | | | |
| 0.6 | 1.67 | 17760 | 20170 | 16440 | 17610 | 18010 | 19040 | 17550 | 38310 | 32820 |
| 0.5 | 2.0 | | | | | | | | 37970 | 32050 |
| 0.4 | 2.5 | 16540 | 20510 | 17210 | 16680 | 16600 | 18450 | 17810 | 35250 | 30570 |
| 0.3 | 3.3 | | | | | | | | 28780 | 23440 |
| 0.25 | 4.0 | 9300 | | | | | | | 25480 | 21310 |
| 0.2 | 5.0 | | 11820 | 9840 | 8260 | 7820 | 11560 | 11360 | 20860 | 17880 |
| 0.133 | 7.5 | | | | 5210 | 5130 | 9190 | 8980 | | |
| 0.1 | 10.0 | (4950) | 4300 | | 4180 | 3950 | 7970 | 7840 | | — |
| DATES | from | 26 Jan. 65 | 15 Mar. 65 | 15 Mar. 65 | 13 Aug. 65 | 13 Aug. 65 | 10 Nov. 65 | 10 Nov. 65 | 17 Mar. 66 | 17 Mar. 66 |
| USED | to | 15 Mar. 65 | 13 Aug. 65 | 13 Aug. 65 | 10 Nov. 65 | 10 Nov. 65 | 17 Mar. 66 | 17 Mar. 66 | 27 Jul. 66 | 27 Jul. 66 |

APPENDIX 5 (2)

| STATION COMPONENT | | SW 27 Jul. 66 | NW 27 Jul. 66 | KALGOORLIE 11 Mar. 65 Z | 11 Aug. 65 Z | Mean Z | 1 Apr. 66 Z | MUNDARING Benimore 25 Aug. 65 | W.S.S.N. |
|---|---|---|---|---|---|---|---|---|---|
| PERIOD (s) | FREQUENCY (c/s) | | | | | | | | |
| 4.0 | 0.25 | 460 | 610 | 126 | 134 | 130 | 180 | 360 | 640 |
| 2.0 | 0.50 | 3280 | 4270 | 1040 | 1100 | 1060 | 1650 | 2890 | 4700 |
| 1.5 | 0.67 | 6560 | 8460 | 2420 | 2600 | 2540 | 4140 | 6490 | 10350 |
| 1.33 | 0.75 | | | 3480 | 3820 | 3650 | | | |
| 1.0 | 1.0 | 16790 | 20470 | 8240 | 9560 | 8900 | 17390 | 20000 | 26000 |
| 0.8 | 1.25 | 24890 | 29070 | 16390 | 19900 | 18150 | 41020 | 36770 | 35690 |
| 0.75 | 1.33 | 26730 | 31610 | 19450 | 24140 | 21800 | 55150 | | |
| 0.6 | 1.67 | 32420 | 36680 | 26440 | 35780 | 31200 | 87710 | 63180 | 37160 |
| 0.5 | 2.0 | 34240 | 38700 | | | | | 79640 | |
| 0.4 | 2.5 | 30240 | 34430 | 22700 | 31530 | 28900 | 110160 | 88990 | 28940 |
| 0.3 | 3.3 | 22110 | 27850 | | | | 127110 | | |
| 0.25 | 4.0 | | | | | | | | |
| 0.2 | 5.0 | 11830 | 14520 | 18560 | 26830 | 22000 | 128660 | 112970 | 12630 |
| 0.133 | 7.5 | 5260 | 7520 | | | | | | |
| 0.1 | 10.0 | | | (13580) | 24790 | 16500 | 60510 | 167420 | |
| DATES | from | 27 Jul. 66 | 27 Jul. 66 | - | - | 26 Jan.65 | 17 Mar.66 | continuing | continuing |
| USED | to | | | - | - | 17 Mar.66 | | | |

# TABLE 1

## Computation form for seismograph calibrations

Date

Station:

Seismometer: Type $f_M =$ $sec^{-1}$ $M =$ gm $R_C = R_R . R_B . 10^{-4} =$ ohms

Galvanometer: Type $Tg =$ sec

| T (sec) | $T^2$ | $f^2$ | $f_M^2T^2$ | $(1-f_M^2T^2)$ | $(1-f_M^2T^2)^2f^2$ | $(\theta_4/\theta_2)^2$ | $\theta_2$ | $\theta_2/A$ | $39.48\ f^2$ | Magnification x $10^3$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Observed | Corr'd ($R_B$) | Corr'd ($R_R$) |
| 4 | 16.00 | 0.06 | | | a | c | | | 2.45 | | | |
| 2 | 4.00 | 0.25 | | | a | c | | | 9.87 | | | |
| 1.5 | 2.25 | 0.44 | | | a | c | | | 17.37 | | | |
| 1.0 | 1.00 | 1.00 | | | b | d | | | 39.48 | | | |
| 0.8 | 0.64 | 1.56 | | | b | d | | | 61.59 | | | |
| 0.75 | 0.56 | 1.77 | | | b | d | | | 69.88 | | | |
| 0.6 | 0.36 | 2.79 | | | b | d | | | 110.15 | | | |
| 0.5 | 0.25 | 4.00 | | | b | d | | | 157.92 | | | |
| 0.4 | 0.16 | 6.25 | | | a | c | | | 246.75 | | | |
| 0.3 | 0.09 | 11.09 | | | a | c | | | 437.83 | | | |
| 0.2 | 0.04 | 25.00 | | | a | c | | | 987.00 | | | |
| 0.13 | 0.02 | 56.25 | | | | | | | 2220.75 | | | |
| 0.1 | 0.01 | 100.00 | | | | | | | 3948.00 | | | |

$G^2 = (\bar{c}-\bar{d}) / (\bar{a}-\bar{b})$

= /

= /

=

G =

$K^2 = 2\pi M\ R_R\ (R_B+R_c) .\ 10^9/G\ (R_R+10,000)$

= 6.28 x x x x $10^9/$ x

= /

=

K =

$A = K.Ed.\ 10^{-1}/M\ (R_B+R_C)$

= /

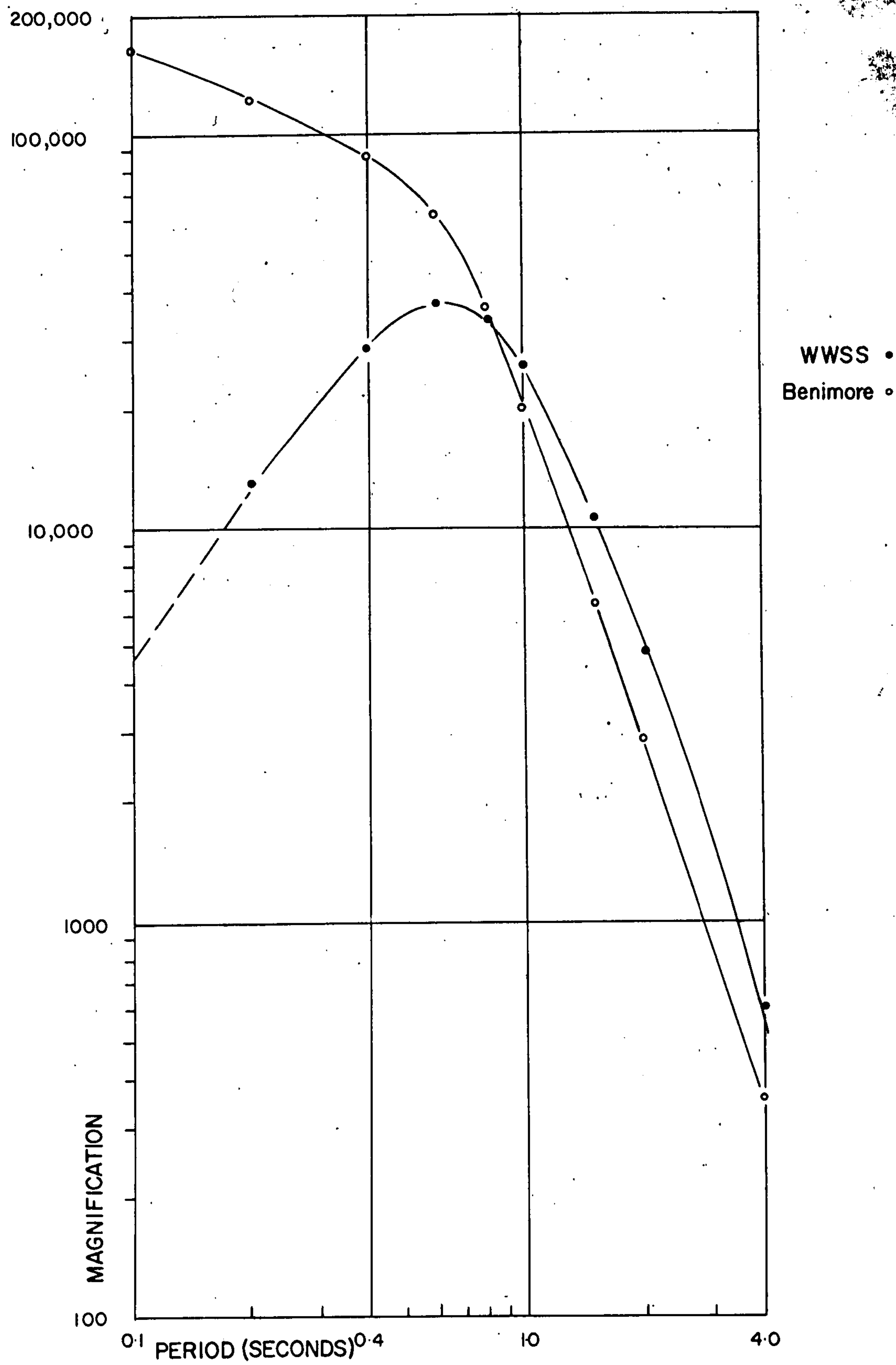
= /

=

1 /A=

$Mag = (2\pi f)^2\ \theta_2/A = (39.48\ f^2)$

Correction Factors: For $R_B$ ; $R'_B/R_B$ = ; For $R_R$: $1 + R_R/(R_c+R_R)$ = ; $1 + R_R/2\ (R_c + R_R)$ =




# CALIBRATION CURVES
# MUNDARING VERTICALS

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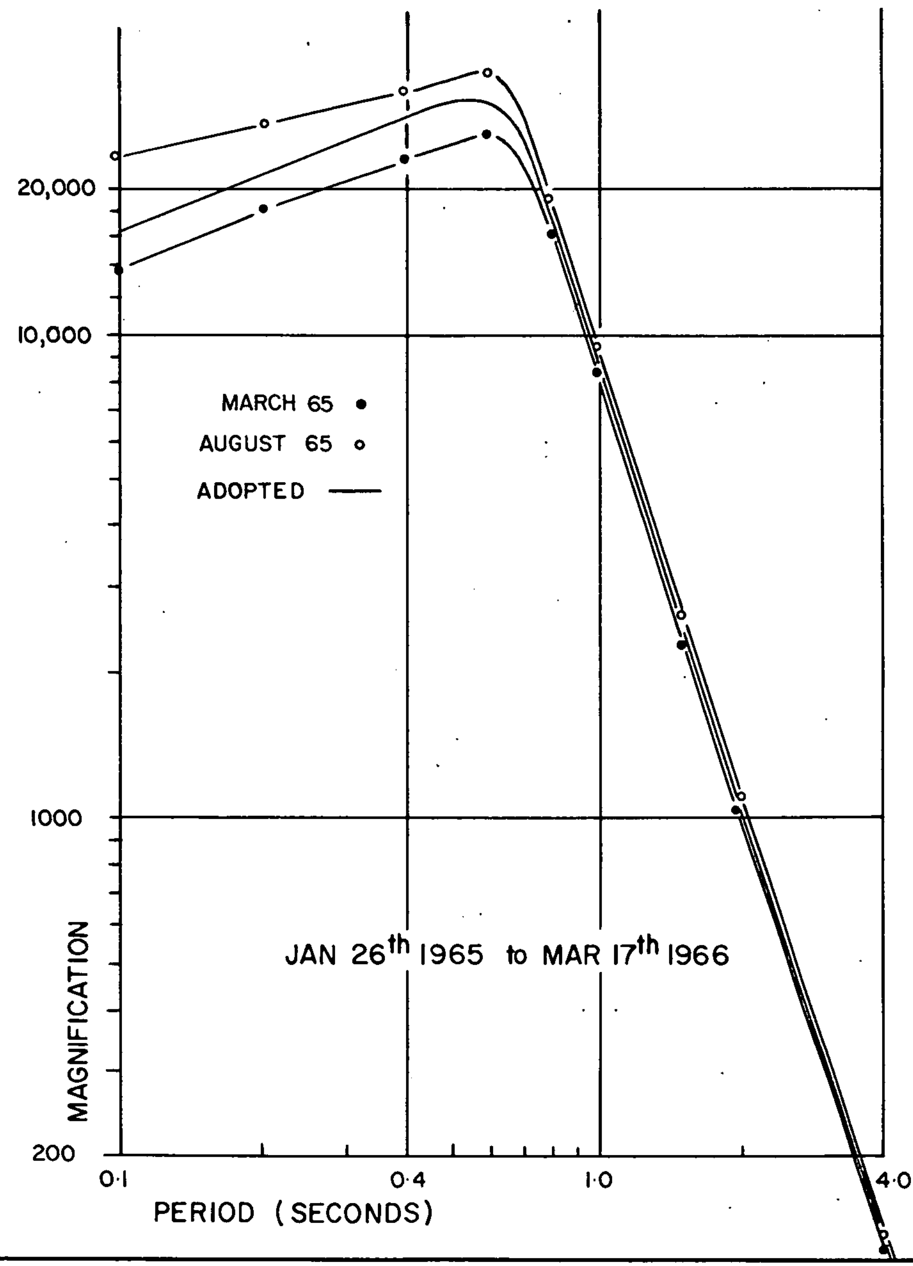
TO ACCOMPANY RECORD No. 1967/46

# CALIBRATION CURVES
# KALGOORLIE VERTICALS



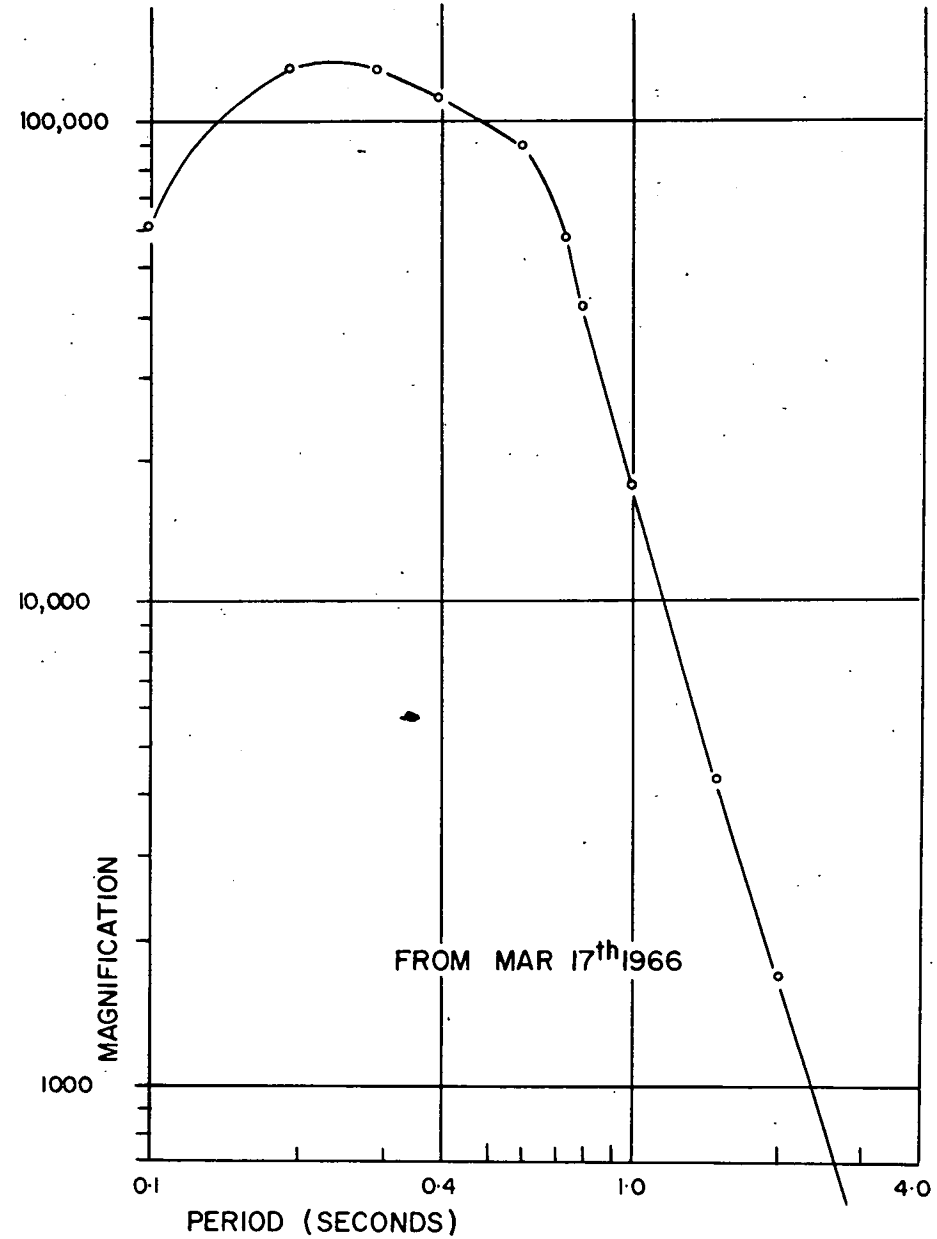




PLATE 2

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TO ACCOMPANY RECORD No. 1967/46

# CALIBRATION CURVES
# KALGOORLIE HORIZONTALS

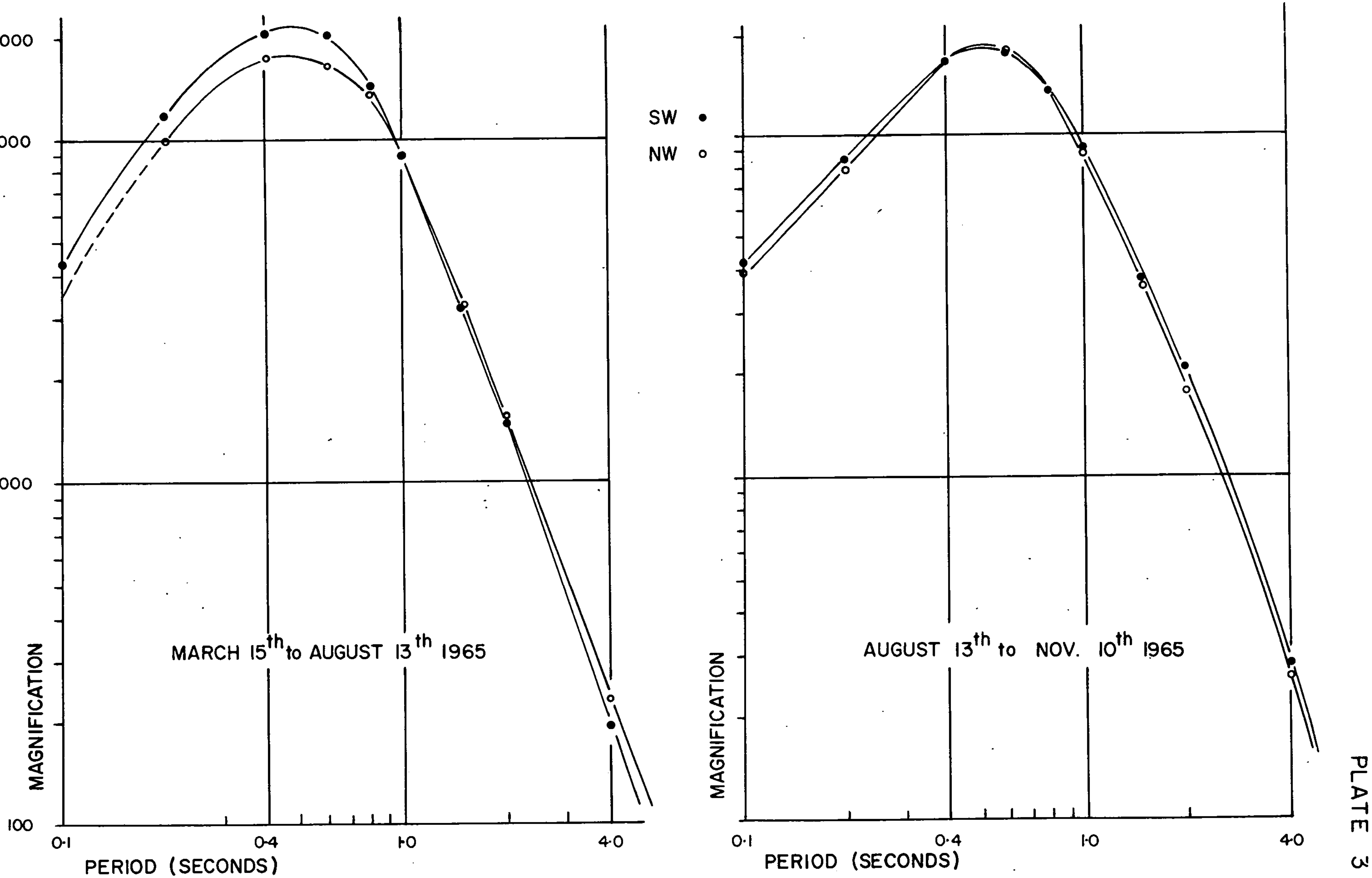


PLATE 3

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TO ACCOMPANY RECORD No. 1967/46

# CALIBRATION CURVES
# KALGOORLIE HORIZONTALS

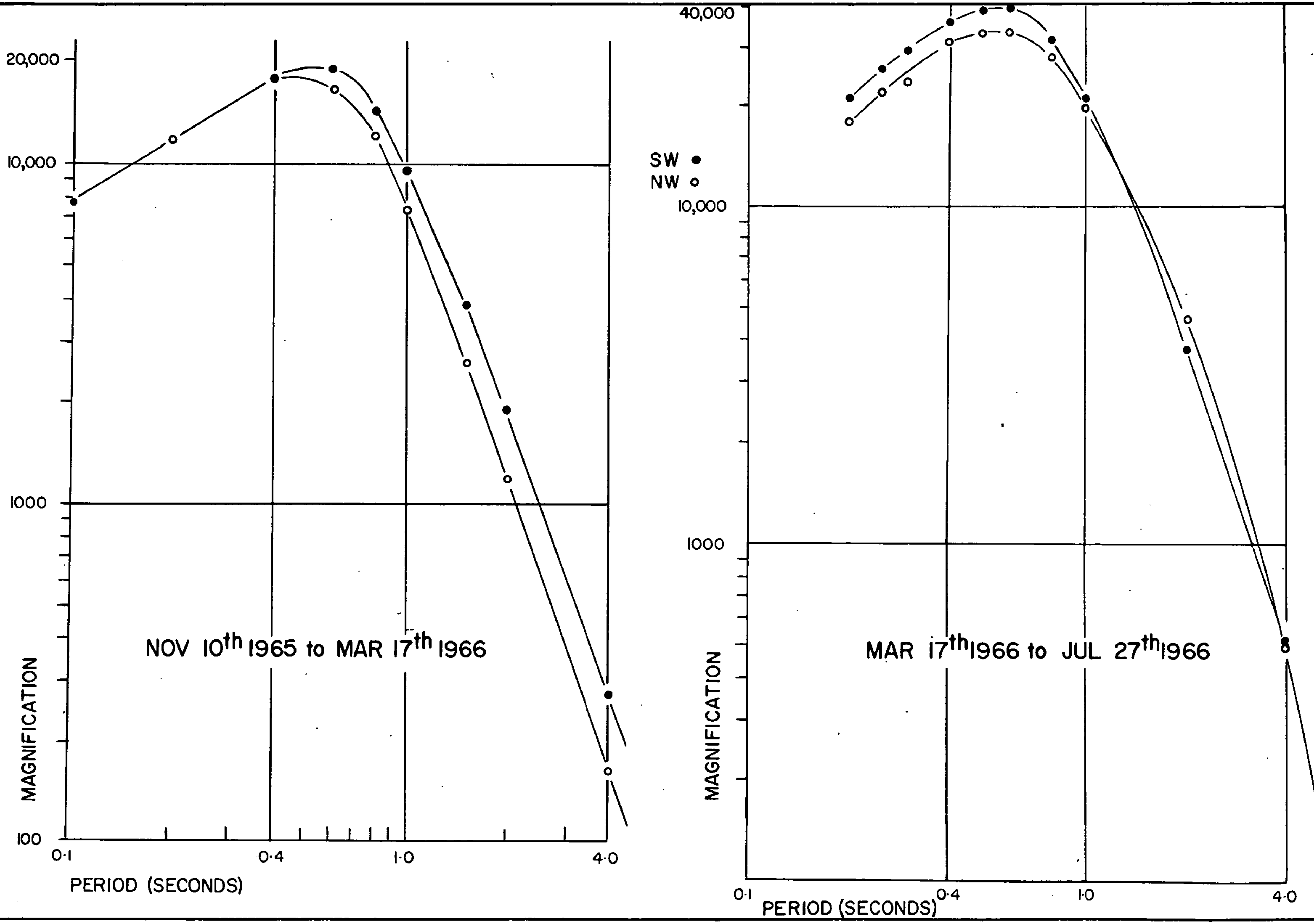


PLATE 4

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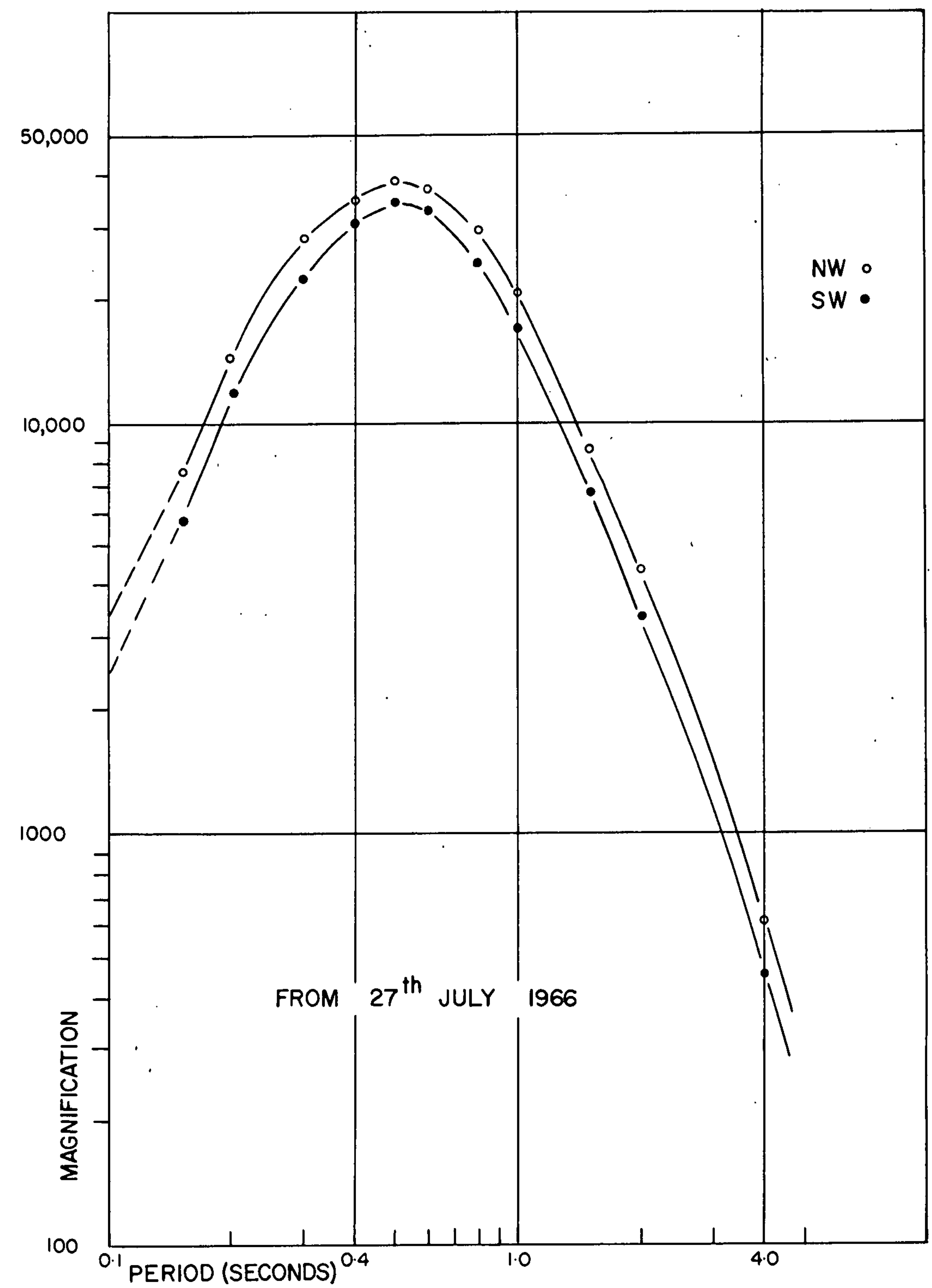
TO ACCOMPANY RECORD No. 1967/46

PLATE 5




# CALIBRATION CURVES
# KALGOORLIE HORIZONTALS

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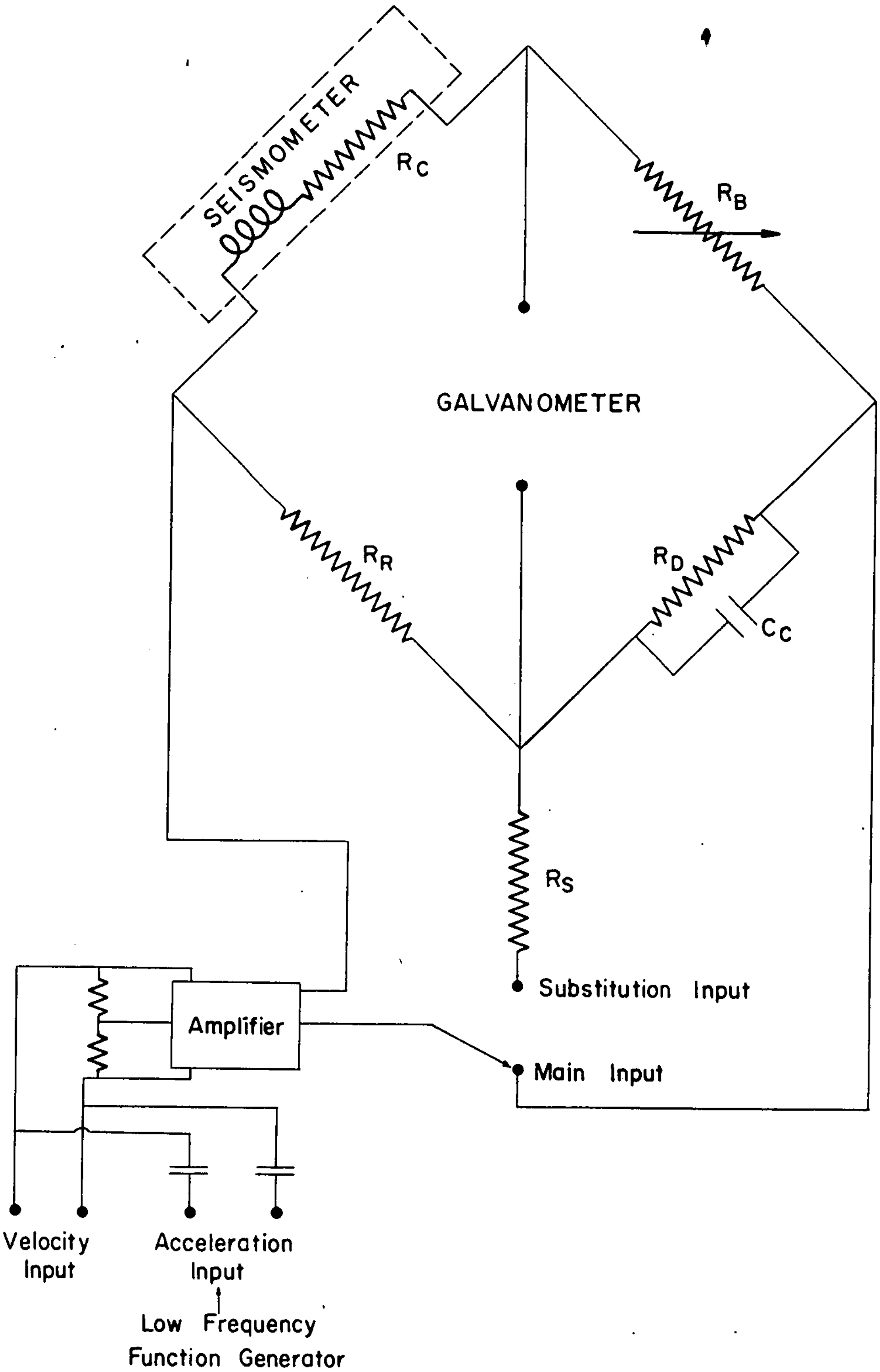
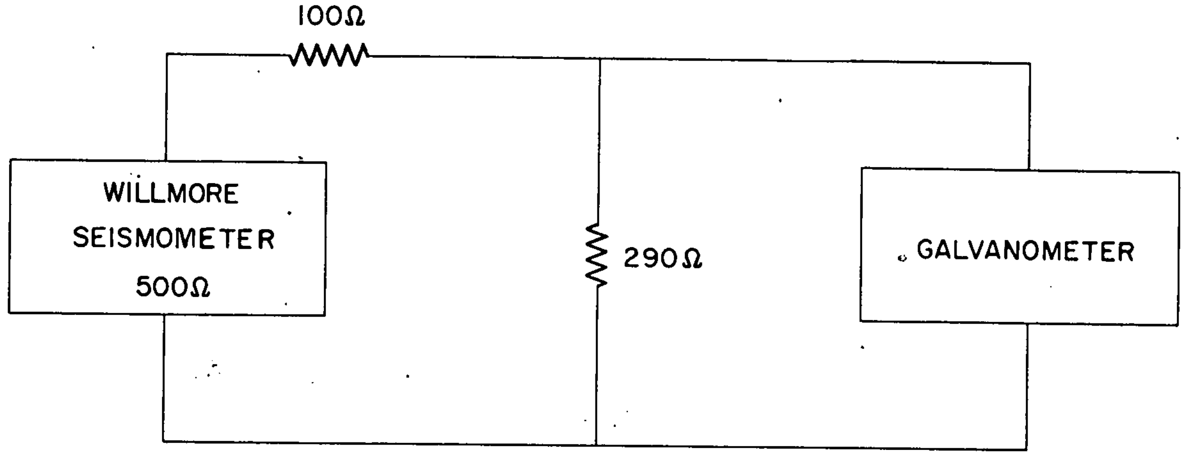
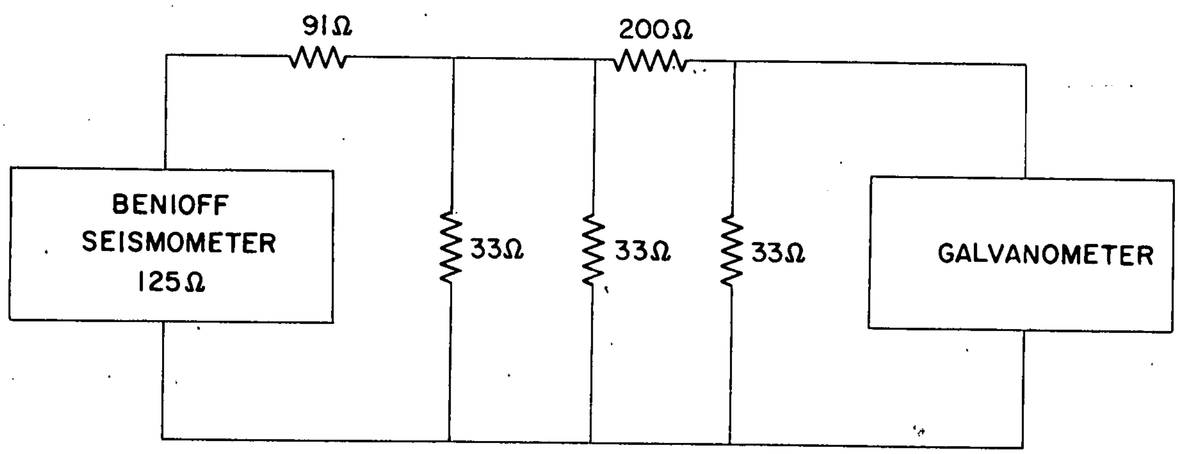



## CIRCUIT DIAGRAM FOR WILLMORE BRIDGE METHOD OF CALIBRATION

VERTICAL




HORIZONTALS




KALGOORLIE SEISMOGRAPH

CIRCUITS

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