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SEA LEVEL MEASUREMENTS USING THE NEYRPIC BUBBLER PRESSURE GAUGE

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INTERNAL REPORT 22

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NATURAL ENVIRONMENT RESEARCH COUNCIL

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Addendum - 1974

Because of a continuing demand this Report is being reprinted. Neyrpic gauges continue to be used for temporary tide gauge installations; a longer term installation on the Inner Dowsing Light Tower in the North Sea produced data for 27 months with a gap of only one day. The gauges now manufactured differ from the one described here in that the standard chart ranges are now 0.5 m and p.10 m, and the case is made of fibreglass. These newer gauges, having a slightly smaller chart width, appear to be less prone to the timing errors described on page 13. Details of the use of these gauges in an extensive regional survey are given in Pugh, D.T. and Waller, W.R.L. (1974).

References

Pugh, D.T. and Waller, W.R.L. 1974 Sea level measurements in the Wash Bay. Proceedings of the 14th International Conference on Coastal Engineering, Copenhagen, 1974. Denmark: Danish Organising Committee and Danish Hydraulic Institute, 1974.

The Institute of Coastal Oceanography and Tides is now part of the Institute of Oceanographic Sciences.

Tests of the Neyrpic bubbler pressure gauge

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Tests of the Neyrpic bubbler pressure gauge

Introduction

Accurate measurements of sea level have traditionally been made using stilling well and float gauge installations. However, because stilling wells are expensive and require a vertical structure such as a pier or harbour wall for support, they are not suitable for temporary installations or for installations on open coasts with large drying areas. The Institute of Coastal Oceanography and Tides has a requirement for a versatile instrument which may be easily installed, particularly on open coasts, as part of its programme to monitor sea level around the British Isles. Because bubbler pressure measuring systems have this versatility it was decided to investigate the physics of such systems and to test a commercially available gauge, the Neyrpic "Telimnip", both in a stilling well and on an open coast. This report contains details of the tests and a summary of the theoretical analysis. A more detailed report on the physics of bubbler gauges will be published elsewhere. Earlier tests at the Institute had shown the less elaborate Negretti and Zambra bubbler gauge to be unsuitable (G. W. Lennon and D. L. Leighton, I.C.O.T. Internal Report No. 11)

1: The bubbler gauge principle

The bubbler system is attractively simple. It consists of a supply of compressed gas, a pressure reducing valve, a gas flow meter, a length of tubing which leads underwater to the gas outlet, and a pressure measuring device, for example an aneroid capsule or a manometer, which records the pressure necessary to force gas out through the underwater end of the tubing. At the underwater outlet, for low rates of gas escape, the gas pressure is equal to the water pressure. This pressure may therefore be used to calculate the head of water above the outlet, using the elementary relationship:-

$$\zeta = \frac{P_t}{\rho_w . g}$$

where ζ is the water level above the gas outlet,
P_t is the water pressure,
ρ_w is the mean water density above the gas outlet
and g is the gravitational acceleration.

The steady flow of gas along the pressure tube connecting the air supply and pressure measuring device to the pressure outlet will be driven by a pressure gradient along the pipe. Thus the measured pressure is higher then the true water pressure by an amount which depends upon the tube dimensions and the rate of gas flow. Because of this, and to conserve the supply of compressed gas, the bubbling rate should be as low as is consistent with good pressure measurements. However, if the supply of gas is too low, the pressure in the system may be unable to increase as rapidly as pressure changes at the outlet due to increasing water depth. Consequently water will be forced into the system until the pressures balance, and the recorded pressure will not be a true measure of the water head above the gas outlet.

In practice the procedure adopted is to calculate the bubbling rate necessary to follow rates of change of water level due to tides (typically 2 metres per hour), and to calculate the corresponding correction for pressure drop along the connecting tube. For normal bubbling rates, connecting tubes of internal diameter greater than 4 m.m., and less than 100 metres long, this correction of less than 0.01 M of water head equivalent.

For the rapid increases of water level due to waves (typically 2 metres per 10 seconds) the system effectively has a constant gas mass. Gas escapes at the trough of a wave but for the remainder of the wave cycle water is forced into the system and a correction is necessary. It may be shown that this correction is reduced if the main volume of the gas system is at the underwater end of the tubing, where it acts as a buffer for fluctuating water pressures. For very accurate work it is also necessary to consider the effects of varying gas density in the pressure tube due to pressure and temperature changes.

The formulae which are used for calculating minimum bubbling rates, tube pressure drop corrections and wave corrections are summarised in the appendix. Using the wave correction theory it has been possible to design a non-bubbling pressure gauge which uses the same principle of gas pressure transmission, but dispenses with the continuous air flow down the connecting tube; therefore pressure gradients in the tube are smaller. This gauge is similar to gauges which use a partially inflated bag, but has the advantage of more exact datum determination. The principle has been verified by tests over a tidal cycle using the Neyrpic gauge and a long period test of a non-bubbler system on the open coats installation at Hilbre Island shows that longer period results are possible.

2. Description of the Neyrpic gauge

The gauge is described in detail in the manufacturer's literature and in the handbook, from which Figures 1 and 2 are derived. The standard unit consists of:-

1. A weatherproof alloy casing which houses the recording strip chart, and which has a window through which the chart may be read.
2. A stainless steel mercury manometer and float system.
3. A pressure reducing valve and compressed air cylinder.
4. An underwater pressure point and connecting tubing.
5. A box of spare parts and fittings and a handbook (in English)

These will be described briefly, in turn.

2:1 The casing and recorder

This measures 0.70 x 0.50 x 0.16 metres, and weighs 26 kg. It is necessary to mount the recorder vertically so that there is no friction as the float rises in the manometer tube, and so mounting with a spirit level is recommended. Fine adjustment for the vertical alignment is made by screw adjustments at the top and bottom of the casing. The strip chart recorder is driven by clockwork with manual rewind or, as an optional extra, with battery rewind. With manual rewind the running time is a month, but four months is possible with battery rewind. The useful chart width is 0.30 metres, and the chart advance speed is 2.5 or 5.0 m.m. per hour. At extra cost speeds of 10 m.m. per hour and 20 m.m. per hour are possible, but the latter only on gauges with battery rewind. For tidal measurements the 10 m.m. per hour speed is generally suitable, but the lower speeds are too slow for compatability with the potential elevation measuring accuracy of the instrument. The direction of travel of the chart is vertically from top to bottom over the chart table.

A roll of chart paper is about 15 metres long so that at 10 m.m. per hour a roll will run for more than 60 days.

2:2 The manometer and float system

The illustrations show the short manometer (0.50 metres) which is used for the 0-3 metre and 0-6 metre ranges. The 0-9 metre, 0-12 metre and 0-18 metre ranges use a longer (1.50 metres) manometer. In either case the manometer is rigidly attached below the right hand side of the recorder casing. The longer manometer has a narrower vertical limb and a smaller reservoir than the short manometer and therefore requires less mercury for operation. The exact amount of mercury required depends upon the range and water density to be measured, but for fresh water on the 0-12 metre scale 3.8 kg. is required whereas 6.2 kg. is required on the 0-6 metre scale. During operation the level of the mercury in the vertical limb is sensed by a stainless steel float which is connected by wire over a pulley to a counterweight. Movement of the float rotates the pulley (A), and this rotation is transmitted to a second rigidly attached pulley (B). A wire loop around this second pulley, and around a third pulley on the other side of the recorder, is used to move the writing pen laterally over the chart paper. The pen is attached to this wire by a stainless steel assembly. The pendrive wire is tensioned at the left hand pulley. When the instrument is supplied, one of the pair of penwire pulleys is marked with an M, and this should be mounted on the manometer side of the instrument. The ratio between the radii of the pulleys A and B affects the sensitivity of the instrument. The float counterweight pulley (A) is used as a control on the water density correction; fresh and "sea water" density (undefined) scale pulleys are available. The full range of the instrument is controlled by the radius of the second pulley (B), which is largest for the 0-3 metre range, and smallest for the 0-18 metre range. Further details of this scaling are given in the appendix.

The final calibration adjustment of the instrument is made by the diameter of the compensating cylinder which controls the depression of the mercury level in the reservoir coincident with mercury rising in the vertical limb. The counterweight is protected by its own vertical tube, and as previously emphasised, the instrument should be mounted vertically so that friction between the inner walls of the vertical tubes and the float and counterweight is small.

2:3 <u>The air supply</u>

Air for bubbling through the system is supplied from a high pressure cylinder, through a constant pressure reducing valve. For the first I.C.O.T. installations British Oxygen Company cylinders containing 40 cubic feet of compressed air were used and these were fitted by an adaptor to the Neyrpic reduction valve. This valve has a meter for reading the high pressure level, and a second meter for reading the low pressure level. This lower level is normally set to 3 Bars, but for measurements of water levels in excess of about 10 metres, a value of 5 Bars is better. (These tests were made with a low pressure of 3 Bars). For more recent installations British Oxygen Company reduction valves have been used, with 60 cubic feet capacity aluminium diving cylinders of compressed air. These have the advantages of larger capacity, slightly reduced weight, and are more easily recharged.

Control of the pneumatic circuit is effected through the brass connection block mounted on the left hand side of the recorder case (Fig.2). There are four connections:-

a) For the low pressure air supply.

b) This air supply passes through the bubbler monitor sight chamber at a rate controlled by an adjustable nut at the top of the block. Thence it passes down the pressure tubing to the underwater outlet via the snap connection.

c) For purging the underwater system it is possible to short circuit the bubble monitor. The snap connection is attached to the purge outlet, through which the more rapid flow of gas is controlled by a knob on the front of the block. The snap connector from the connection tubing automatically seals if it is disconnected, thus preventing entry of water into the system under pressure through the underwater outlet during changeover.

d) The pressure in the bubbler tubing is transmitted to the manometer by a further short length of tubing.

A single cylinder of 40 cubic feet of air will last for in excess of six weeks at a bubbling rate of 60 per minute. Similarly a 60 cubic feet bottle would last in excess of 13 weeks at 40 bubbles per minute.

2:4 <u>The pressure point and tubing</u>

Tubing normally used with the Neyrpic gauge has an internal radius of about 2 m.m. and an external radius of about 3 m.m. I.C.O.T. installations now use nylon tubing of 0.15" internal diameter and 0.25" outside diameter. According to the handbook the maximum length of connecting tubing is 300 metres, but longer lengths would be possible if a pressure drop correction were made, or if larger diameter tubing were used. Connectors for joining lengths of tubing are available from Neyrpic, but ordinary brass brake hose connectors have proved satisfactory, and more recently connectors and adaptors from the Simplifix range have been used. According to the handbook the tubing should slope down to the pressure point at an angle of not less than 1^{o}.

The pressure point for tidal measurements is slightly larger than the pressure point for ordinary measurements, presumably to absorb the water which enters due to waves.

The former is 0.16 metres deep whereas the latter is 0.05 metres deep. Both are made of anodised steel in a hemicylindrical form of diameter 0.15 metres. The bottom is open but protected by a wire mesh, and gas escapes through a small (3 m.m. diameter) hole about 10 m.m. above the bottom. The wire mesh tended to become blocked with silt when the instrument was installed in a stilling well and so a later model, made for Hilbre, had no mesh. The tubing connects at the top of the pressure point. Ranges in excess of 18 metres would be possible if a switching system between a series of pressure points were developed.

If measurements are to be made in the presence of large amplitude waves, Neyrpic recommend one or more wave filters connected in series at the tube inlet to the manometer. These have a time constant of about 10 seconds while the gas permeates through a sintered metal membrane. These filters were not used for early I.C.O.T. installations as the natural time constant of the tubing and the manometer provided sufficient filtering, and because the accuracy of the gauge is slightly increased by the small pressure fluctuations reducing stiction in the recording system, but recent installations where only a few tens of metres of tubing were used have required a single filter. This one filter was sufficient to damp out waves, but without it pen movements gave unacceptably wide traces.

2:5 Accessories

The instrument is supplied together with a box of accessories which contains a spanner for adjusting the bubbling rate, a chart, a bottle of ink, a bottle of oil and two bags of dehydrating material. The latter is very necessary to keep the chart dry; a damp chart has distorted dimensions and may run unevenly over the driving mechanism, resulting in elevation and timing errors. A spare set of pulley wires is also provided.

Copies of the handbook are available in French, English or Spanish. The English version has suffered a little in translation. In particular the table on page 3 which gives the quantities of mercury required for different ranges and density scales lists "saft water" for fresh water. This table also contains unexplained additions to the basic quantities. In general the explanation for routine setting and using of the gauge are adequate, but some diagrams (e.g. E3225-4) referenced in the text do not exist and there is no explanation of how to change the scale or density factors. Smaller details not dealt with are the purpose of the manometer compensating cylinders, the fitting of the pen carriage wire, and the vertical adjustment of the strip chart assembly for different ranges. The latter is done by unscrewing the table and raising it to a higher or lower position, so that the pen fits properly onto the paper from the new carriage wire position.

2:6 The instrument tested at ICOT

The instrument initially delivered to I.C.O.T., No.6832, was capable of measurements in the range of 0-3 metres and 0-6 metres for both fresh and salt water. The longer manometer, and pulleys for 0-9 metre and 0-12 metre ranges were delivered later; although this manometer had been calibrated with a fresh water compensating cylinder, this calibration did not include the pulley system gearing which had been supplied earlier.

First tests were made with the 0-6 metre range using two pressure points. Subsequently tests were made using the 0-12 metre range on the freshwater scale. This scale was preferred to the seawater scale because the density of the latter is not defined, though in fact the "freshwater" scale was found to be accurate for a density of 1010 Kg/Metre^3. Because the gauge measures pressure it was decided to calibrate the gauge as a pressure measuring device and to calculate levels of water head in terms of the pressure. A gauge set accurately for a fresh water density would read high by 2.5% for sea water of density 1025 Kg/M^3.

The instrument was calibrated on the 0-12 metre fresh water scale on the basis of a Van de Casteele test of the bubbler system in the Alfred Dock stilling well, using water densities calculated from the temperature and salinity in the well. This calibration factor was then applied to correct readings made during a Van de Casteele test on the non-bubbler gauge in the well, and during a similar test on the bubbler gauge fixed in the River Mersey level with the stilling well pipe outlet.

Installation of the gauge at Hilbre was completed by October 1970, and a Van de Casteele test was made against tide pole readings on 16 November 1970. The gauge was then used for routine collection of data at Hilbre, and for an extended test of the non-bubbler system.

Finally a different gauge, No. 7033, was used for bubbler and non bubbler tests against a flight of tide poles under calm conditions at Nefyn, Caernarvonshire.

3: Well tests

3:1 Tests on the 0-6 metre range

The equipment was installed in the Alfred Dock stilling well and tide gauge hut and then, on 11 December 1969, a Van de Casteele test was made over a cycle of a 9 metre spring tide. As the gauge attempted to follow the rising tide there was an increasing error which was eventually found to be due to leaks in the manometer compensating cylinder seal. Small leaks in a bubbling system are not important, provided that the bubbling rate is sufficiently high to cope with increasing water levels. In this case the leak was large enough to prevent satisfactory monitoring of the rising tide, but not large enough to spoil records on the falling tide. When the system was purged the gauge read the correct level, and then the above pattern of errors was repeated. The record on the falling tide was more satisfactory.

It was noticed that air was emitted from the underwater end of the system, not in individual bubbles, but in bursts every five or ten seconds which might imply step changes in gauge readings. However the accuracy of the measurements on the falling tide shows that these step changes had an effect of less than a centimetre, as would be expected theoretically.

3:2 Bubbler gauge measurements in the well

Measurements throughout a spring tide cycle on 6 April 1970 are plotted in Figure 3. The Neyrpic readings have been corrected for water density in the well assuming that the instrument was correctly calibrated for a fresh water scale.

The systematic slope of the difference curves shows that either the assumed calibration factor or the water density computed from temperature and salinity is in error.

Suspended sediment would increase water density above the computed value but this would increase the trend, so it appeared that the gauge was set for a water density greater than 1000 Kg/M^3. The results of this test were therefore used to compute a calibration factor for the gauge on the assumption that the density of the well water was correctly computed from the temperature and salinity readings. This gave a calibration factor:-

(9900 ± 5) Newtons per metre ^{2} per metre of chart readings,

at 16°C, with the standard error quoted. This factor was used for subsequent reductions of date from Alfred Dock tests, although calibration using a dead weight tester later shows it to be slightly low because the suspended sediment in the well water gave it a higher density than that calculated from the temperature and salinity measurements. Details of this absolute calibration are given in section 6:3.

Backlash difference between the rising and falling tide is (0.050 ± .008) metres, excluding readings close to zero, where the backlash error disappears. The difference between the first and last readings at the same water level is 0.018 metres.

Apart from error due to backlash, the standard deviation from the least - squares-fit line is 0.014 metres on the rising tide and 0.006 metres on the falling tide.

3:3 The Non-bubbler gauge in the well

Figure 4 shows the elevations computed from gauge readings for the non-bubbler gauge throughout a tidal cycle on 11 March 1970. The underwater element used was an ordinary 5 gallon oil drum which, with the length of tubing used, had a (Vo/Ao) (Appendix 6) coefficient of 0.40 Metres.

The least square lines fitted to the readings are:-

rising tide: (Wcalc - WT) = (-0.2151 ± 0.0036) + (0.0006 ± 0.0005) (WT)
with a standard deviation 0.0082 Metres

falling tide: (Wcalc - WT) = (-0.1096 ± 0.0018) + (0.0013 ± 0.0003) (WT)
with a standard deviation 0.0053 Metres.

where WT is the true well level in metres

and Wcalc is the well level computed from the Neyrpic reading, the calibration factor, and the density of the well water calculated from temperature and salinity measurements.

The lines are almost exactly vertical, confirming the non bubbler theory outlined in the Appendix. However, the difference between readings at the same level on the rising and falling tides is slightly greater than for the bubbler gauge in the well at (0.105 ± .003) metres. Again the errors apart from the backlash are less than 0.01 metres. The difference between the first and last readings at the same level is less than 0.02 metres.

3:4 Bubbler measurements in the Mersey

To test the gauge performances when not protected by a stilling well, a Van de Casteele test was performed with the pressure point lowered over the dock wall, adjacent to and at almost the same level as the pipe which connects the stilling well to the river. The gauge performance must be checked against an accurate standard which, because of the accuracy required, presents an almost insuperable difficulty.

For these measurements the gauge was checked against the well level as measured accurately with a probe. This is acceptable provided that well densities are used to compute the Neyrpic readings of water elevation, but assumes that the pressure in the river and in the well is the same at the gas outlet level. Fig. 4 shows the trace obtained from the gauge for this test, where one small (2 m.m) division of vertical scale corresponds to about 0.08 metres of water level.

The errors shown in the Van de Casteele plot (Fig. 5) include any errors due to a time lag in the well connecting pipe, but nevertheless, the results are very good. The least square fits to the rising and falling tides are:-

rising tide: $(Wcalc - WT) = (0.9176 \pm 0.0046) + (-0.0016 \pm 0.0009)(WT)$
with a standard deviation of 0.0153 metres.

falling tide: $(Wcalc - WT) = (0.9279 \pm 0.0072) + (-0.0001 \pm 0.0012)(WT)$
with a standard deviation of 0.0155 metres.

Once again the lines are almost exactly vertical, and the standard deviations are at an acceptable level. The backlash between rising and falling tides is greatest at mid tidal levels, with the Neyrpic readings lagging behind those of the well, i.e. in the opposite sense to what might be expected if the lagging were due to the well level lagging the river due to the limited diameter of the connecting pipe. The difference between the first and the last reading, at the same level, is less than 0.01 metres. It appears that the pressure oscillations due to waves tends to reduce the backlash error.

A limited test of the non bubbler gauge in the Mersey on 30 April 1970 through low water on a neap tide showed a backlash error of approximately 0.07 metres. Experiments to try to reduce this backlash error still further resulted in subsequent measurements being made with a small vibrating motor attached to the manometer, and with a small balancing weight to reduce pen pressure on the chart. When these experiments, which are described in more detail in section 6, were completed, arrangements were made to install the gauge at Hilbre Island.

4. Tests on the Hilbre installation

4:1 Description

Hilbre Island, situated at the mouth of the Dee Estuary, is accessible over the sands from West Kirby only during the lower half of the tidal cycle. At low water it is protected from the full effects of waves from the open sea by the Hoyle Bank, but once the level of water rises above five metres it can be subjected to quite severe conditions. This and its proximity to ICOT were the reasons why it was chosen for the tests. A gauge has been in operation at Hilbre since 1853: this consists of a stilling well connected to the sea by about 100 metres of syphon pipe. Figure 7 shows the conditions at the north end of the island at low springs. Initially the pressure point was installed further north than its final position, and connected to the recorder in the tide gauge hut by tubing laid along the sea bed and the syphon pipe gulley; however, wave action was too severe: the point was washed into deeper water and the tubing was parted at joints by severe surging in the gully. The final position for the pressure point (Figure 7) was selected because Liverpool Bay chart Datum level was accessible at the bottom of an almost vertical rockface some 1.5 metres high.

Details of the installation for the pressure point are shown in Figure 8. The connecting tubing was laid along the track of an old lifeboat slipway, and protected along its length by leading it inside ¾" electrical conduit piping, which was further protected, where necessary, with a covering of cement. In all, 172 metres of conduit was used and affixed to the rock with conduit saddles and 4" screws. Tube connections were made in conduit connection boxes.

One advantage of using the lifeboat slipway was that it provided a gradually falling track for laying the conduit. This gradual fall makes it impossible for water to condense and gather at low points in a tube installation. If water were trapped at a low point in a tube a local manometer might be set up, causing the pressure at the mercury manometer to be different from that at the underwater outlet.

4:2 Bubbler Tests

Two tide poles, constructed from 20 foot lengths of 3" outside diameter iron piping were erected to give the true water level in the open sea. The accuracy with which a tide pole may be read depends upon the sea conditions, and only rarely is it possible to read to an accuracy of 0.02 metres. However, as no better method is yet available, their use was unavoidable. The first pole was mounted next to the pressure point, but to cover the top of the tidal range it was necessary to erect the second pole about 100 metres nearer the tide gauge hut. Readings of water level at the lower pole may be directly related to the pressure being measured on the Neyrpic, but the levels read on the upper pole may differ slightly because of gradients on the water surface due to water currents. The erection of the poles was completed on 14 November, and a Van de Casteele test was made on 16 November.

Figure 9 shows the results of this test. The Neyrpic readings have been corrected for water density (which increased linearly with elevation), for the pressure gradients along the tube, and for the effects of waves. The upper tide pole readings have been corrected to remove a systematic difference between them and the readings of the lower pole. On the rising tide simultaneous readings of both poles showed that the upper pole was reading (0.08 ± 0.06) metres high, consistent with the strong observed E-W current across the headland. On the falling tide the water gradient and the current direction were reversed, with the upper pole reading (0.06 ± 0.03) metres lower than the pole by the pressure point. These currents were estimated in excess of 2 metres per second (ca. 4 knots). For a part of the falling tide it was too dark to read the level on the lower pole to any accuracy, and these readings are circled in the diagram.

After correcting the upper pole readings for gradient on the water surface no systematic difference is detectable between Neyrpic readings on the rising and falling tides. This is partly because the vibrating motor was connected, partly because of the agitation of the waves, and partly because of the scatter of the data. A single least squares line was fitted to all of the data:-

$$W_{calc}-W_{pole} = (0.018 \pm .014) + (-.0032 \pm .0025)\,(W_{pole})$$

with a standard deviation of 0.046 metres

where Wcalc is the water level calculated from the Neyrpic readings and calibration factor, using the water density as calculated from temperature and salinity measurement throughout the tidal cycle, and

Wpole is the water level computed from pole readings.

The standard deviation of the differences from the best straight line fit is greater than for measurements made in the Mersey, but most of this scatter is owing to errors in reading the tide pole, particularly at water levels greater than 5 metres, when wave amplitudes varied between 0.5 and 1.0 metres. This is confirmed by a comparison of Neyrpic levels with levels measured in the stilling well. In this case the Van de Casteele plots show much less scatter with a standard deviation of 0.025 metres. It would have been unfair to design the test to use the well readings to check the performance of the Neyrpic gauge as the well input was about 100 metres from the gauge outlet, and the characteristics of the well response were unknown. If, however, we assume the errors involved in measuring a "true water level" by the well system and the pneumatic system are independent, then both gauges are accurate to better than 0.025 metres. The datum of the gauge agrees to within 0.018 metres with the datum obtained by levelling, and within the error of measurement there is no systematic slope on the data.

4:3 The non-bubbler gauge tests

After completion of the Van de Casteele test the gauge was run on a routine basis to gain experience in using it for data collection. 53 days of continuous data from December 1970 and January 1971 have been analysed in detail both harmonically and non-harmonically with a view to developing a standard method of reducing data from temporary installations. Details of the results will be given elsewhere. Standard procedures for making regular, preferably weekly, inspections of Neyrpic installations have been developed (Section 6).

Tests were then made with non bubbler gauge systems to determine whether the principle could be used for long periods. Initially an inverted 1 gallon oil can was used, but this corroded rapidly and the final tests were made using a more substantial 5 gallon oil drum. The (Vo/A) coefficient of the system using this drum was 0.425 metres. To check for long period changes in the datum of the gauge due to absorption of air from the drum by the sea water, the conventinal Légé gauge was used as a standard. The differences between the Légé and the non bubbling daily means are plotted in Figure 10. The gap in data after the first few readings is because the Légé gauge chart was lost and because of large timing errors in the Neyrpic gauge records (see section6:2).

Fitting a straight line through the data gives an average drift rate after non bubbler corrections have been made of 0.157 metres per 100 days or 0.01 Metres in 6.4 days. For accurate work a non bubbler drum of these dimensions should be inflated every week or alternatively, the total drift over a longer period may be determined at reinflation, and a drift correction applied.

5. Tests at Nefyn

Because the open sea tests of the Neyrpic gauge at Hilbre Island were made in conditions which made very accurate readings of the standard tide poles impossible, it was decided to make an open sea Van de Casteele test of a gauge (No. 7030) installed at

Nefyn, Caernarvonshire, against a flight of tide poles installed down the life boat slipway. The opportunity was also taken to make an accurate Van de Casteele test of the non-bubbler gauge in the open sea. Both tests were made over a smaller tidal range than would have been possible near Liverpool.

5:1 Bubbler tests

Figure 11 shows the plot of the Neyrpic errors for both the rising and falling tides. Least squares fitted lines to both the rising and falling tide and to all of the data are also plotted. For the rising tide the best line (1) is:

$$(Wcalc - WT) = (0.031 \pm 0.006) + (-0.0030 \pm 0.0015)\ WT$$

with a standard deviation of 0.009 metres,

and for the falling tide (2) :

$$(Wcalc - WT) = (0.059 \pm 0.005) + (-0.0020 \pm 0.0015)\ WT$$

with a standard deviation of 0.010 metres.

For all the data the best line (3) gives:

$$(Wcalc - WT) = (0.050 \pm 0.007) + (-0.0045 \pm 0.0020)\ WT$$

with a standard deviation of 0.018 metres.

This standard deviation may be taken as an indication of the overall accuracy of the gauge operating on the 0-12 metre range. WT is the true water level measured to within 0.01 metres on the tide poles and Wcalc is the corrected Neyrpic reading of water level. Note that the scale for Figures 11 and 12 is different from that for the previous Van de Casteele plots.

5:2 Non-bubbler tests

The results of the non-bubbler tests are shown in Figure 12 for both the uncorrected and corrected Neyrpic non-bubbler levels. Without the non-bubbler correction the least squares line (1) is:

$$(Wcalc - WT) = (0.031 \pm 0.006) + (-0.0168 \pm 0.0015)\ WT$$

with a standard deviation of 0.008 metres.

When the correction is applied the least squares line (2) is:

$$(Wcalc - WT) = (0.0125 \pm 0.006) + (0.0006 \pm 0.0017)\ WT$$

with a standard deviation of 0.008 metres.

This result confirms beyond doubt the precision of the non-bubbler theory and of the correction term.

In both figures 11 and 12 it is apparent that the Neyrpic has a tendency to read high by about 0.02 metres between 2 and 3 metres but this may be partly because of a levelling error in the tide pole used at this level.

The non-bubbler drum used for this test was the ordinary bubbler pressure point and the (Vo/Ao) term (appendix 6) was calculated from the dimensions of the pressure point, the connecting tubing and the gauge manometer, which gave a factor of 0.27 metres. This use of the bubbler pressure point as a non-bubbler drum is a convenient way of running a Neyrpic gauge where a compressed air supply is temporarily unavailable.

6. Other tests of the gauge

6:1 Experiments to reduce backlash

In order to investigate the causes of the backlash difference between measurements on rising and falling tides, a series of miniature Van de Casteele tests were made with the gauge manometer. The small pressure point was connected directly to the manometer

by a short length of tubing and the gauge readings were recorded as the pressure point was lowered and raised in 0.02 metre steps in a bucket of water.
The theory of the non-bubbler gauge shows that the pressure on the gauge is almost exactly that due to the water head above the outlet for the small pressures (less than 0.25 metres) involved. From these tests it was found that there were three independent causes of the backlash: pivoting of the pen on the carriage wire, friction in the pulley mounting, and friction of the float and counterweight in their tubes. Table 1 summarises the backlash typically associated with these for the 0-6 metre range and the 0-12 metre range in terms of water-head measurement.

Table 1

Backlash cause	0-6 metre	0-12 metre
Pen pivoting	0.013 metres eliminated by balancing pen	0.027
Pulley friction	0.008 reduced by oiling and vibration to:- 0.004	0.032 0.016
Manometer friction	0.003 eliminated by vibrating motor	0.011

Summary of sources of backlash in Neyrpic gauge

These values vary, dependent upon the actual gauge installation, and particularly upon the friction in the manometer tube which increases considerably if the manometer is not vertical. The effects of the frictional factors were measured as grams weight required to move the pulley and float systems forwards and backwards. This was then converted to equivalent water head by calculating the displacement of mercury by the float necessary to overcome these forces. Because the small manometer has a float of approximately four times greater cross section than the long manometer float, the vertical displacement and error is reduced. However, for the 0-12 metre range it was essential to have a small vibrating motor attached to the manometer to achieve the potential accuracy of the instrument. The installation at Hilbre used a 28 volt surplus store motor which ran continuously off a 12 volt car battery for at least a week. During actual sea level measurements the vibrator motor is aided by pressure fluctuations due to wave action, provided these are not too heavily damped along the connecting tube and through the wave filters.

6:2 Timing accuracy

The Neyrpic model initially supplied to ICOT was fitted with a battery rewind clockwork motor which proved capable of running for at least the specified four months per battery. Provided that the record is carefully read the timing may be taken from the chart to within one minute (0.15 mm) at a speed of 10 mm per hour, which is satisfactory for most applications and compatible with an accuracy of 0.02 metres and a rate of change of water level of 2.4 metres per hour. However, for the 0-6 metre range where an accuracy of 0.01 metres is claimed, or for more rapid changes of water level, a chartspeed of 20 mm per hour is necessary, and this is only available on the battery operated model.

The following summarises the timing accuracy of four gauges used at I.C.O.T. measured over periods of one week or more :-

TABLE 2

	Minutes loss per week						Minutes gain per week				
	5	4	3	2	1	0	1	2	3	4	5
Number of occurrences	0	0	2	3	6	7	5	3	2	1	1

Summary of Timing errors

which is satisfactory. However, the original gauge and one of the later gauges gave much larger errors on a few occasions. The original gauge lost 14 minutes in 11 days on one occasion, gained three hours in 9 days on another, and gained 26 minutes in seven days on a third. These three events were associated with mangled chart sprockets and uneven paper drive and the fault has not reoccurred since a regular programme of drying agent replacement which keeps the chart dry and correctly scaled was introduced. The second gauge which gave gross timing errors gained 43 minutes in 8 days and, worst of all, 8 hours in 14 days. This intermittent fault has proved very difficult to trace but both of the faulty gauges were battery driven, and similar faults have been present in battery driven gauges used by the National Institute of Oceanography and by Binnie & Partners. As neither of the clockwork gauges used by I.C.O.T. has developed any timing faults the trouble seems peculiar to battery driven gauges. Because of this possibility of irregular running, a programme of regular weekly checks is essential. Small timing errors may be adjusted by means of a conventional clock rate control. A single unit of adjustment has been found equivalent to a change of rate of 2.5 minutes per day.

The drive shaft from the clockwork motor revolves once in six hours, while the paper drive roller rotates once in nine hours. Between these two is a series of gears and drive rods which have a backlash equivalent to 2.5 mm of chart time. When setting the chart to run at a particular time it is necessary to anticipate the delay due before paper drive takes up, and to advance the pen position accordingly. By setting the pen position against the backlash the delay may be reduced to about three minutes.

6:3 Absolute calibration of the gauge

In order to overcome the difficulties in determining the calibration factor of Neyrpic gauges it was decided to purchase a pneumatic dead-weight tester. This gives an absolute calibration of the gauge accurate to 0.05% using the Budenberg Model 240, which is equivalent to 0.005 metres in 10 metres of water. One advantage of having a calibrating facility is that manometers and pulleys may be interchanged between gauges. The advantage of the portable deadweight tester over the well calibration used in section 3:2 is that the job can be completed by two people wherever the gauge is situated, using the gauge air supply, in less than an hour with the tester, whereas the Van de Casteele test takes over twelve hours. Also, well densities are only approximately determined from measurements of the temperature and salinity of the water as there is an additional load due to suspended sediment.

The amount of suspended sediment in the Alfred Dock well during the test of 6th April 1970 may be calculated by comparing the true calibration factor for the gauge, as determined by the dead-weight tester, with the factor determined on the basis of the well test. The well test calibration factor was:-

(9900 $\pm$ 5) Newtons per metre^2 per metre of chart reading, at 16°C

and the true factor was:

(9926 $\pm$ 6) Newtons per metre^2 per metre of chart reading, at 16°C.

The former is low because the well density was greater than supposed from the temperature and salinity measurements. On this basis, the density increase due to suspended sediments was 2.6 $\pm$ 0.7 Kg per cubic metre. A.R. Halliwell (personal communication) has measured concentrations of up to 1.5 Kg per cubic metre in the "dirty" Mersey river water, and the increased concentration in the well is probably due to the inflowing water lifting sediment from the well floor into suspension. In the Alfred Dock well this would lead to the well level being a centimetre or more below the river level on a 10 metre tide. It is probable that the effect also exists at other stilling well installations.

For reduction of the Alfred Dock tests the apparent calibration factor was used, but for Hilbre, where the sediment load is smaller, the true calibration factor was used.

7. Procedure for routine data collection at ICOT

Although no two installations are identical, the general procedure used at the Institute for obtaining tidal elevation data from an area is summarised here, as it may be helpful for prospective users of pneumatic gauges in general and of the Neyrpic gauge in particular. The process divides naturally into three stages:-

Site selection and installation of the gauge,
Routine inspection and servicing,
Chart reading and computer reduction.

7.1 Site selection and installation of the gauge

The ideal site is one where a vertical greenhart pile or fender is available for attaching the pressure point, where an adjacent hut is available for mounting the gauge, where currents and variations of water density throughout the tidal cycle are small and where one or more Ordnance Survey bench marks are close at hand. It is valuable if someone locally is able and willing to make daily checks of the timing and level of the gauge. These conditions are most often found on a pier in a harbour, but care must be taken to make sure that such places are well connected hydraulically to the open sea and that density variations are not affected by irregular run off of fresh water. Very local gradients on the water surface due to local currents must be avoided; a steady current speed of 0.45 metres per second is equivalent to a surface depression of 0.01 metres, but the depression is proportional to the square of the speed so that at 2.0 metres per second the depression is 0.20 metres.

Where a vertical installation is possible the pressure point may be attached on the lower part of a stout board which is then fixed at a moderate low water by means of coach bolts through the upper parts of the board. Where the installation is at the end of a slipway or other slope, then only a few minutes, at extreme low waters, are available for fixing. This made the Hilbre installation very difficuly; alternatively divers may be used as was the case with the Nefyn installation. Ordinary ¾" electrical conduit has been used for protecting the pressure tubing to the gauge. Each installation is levelled from the centre of the air outlet hole of the pressure point into the Ordnance Survey levelling system. On a vertical structure the length along the fixing board may be measured before mounting, and the level taken from the top of this board. Where this is not possible an alternative method is to make a Van de Casteele test against a series of tide poles which have been levelled into the national system, and then extrapolate to zero gauge reading to find its datum level. Where possible a metric tide board is installed close to the gauge for checking levels at the weekly inspections.

7:2 Routine inspection and servicing

Where possible daily checks should be made of the timing accuracy, and of the gauge readings of water level by comparision with readings on a nearby pole so that, in the event of failure, the amount of data lost is minimised. The local Piermaster or Harbour Master who has an interest in the results, is usually cooperative, and able to do this. Any failure of the gauge is reported to ICOT so that arrangements may be made for immediate repairs.

At intervals of about a week, and of not more than a fortnight, a more elaborate inspection is necessary. This includes timing and level checks, but also involves a check of the gauge zero and air supply, removal of the chart if necessary, and changing of the drying agent.

A detailed procedure has been developed based on a standard form. Appendix 7 contains a specimen form and a set of the explanatory notes which accompany it. To date this more elaborate check has only been made by ICOT personnel.

7:3 Chart reading and computer reduction

When a chart is returned to ICOT it is checked against the corresponding inspection forms for timing and zero drift errors. Hourly heights are then read off and punched on cards for computer correction. These hourly height values are in metres, which, for a resolution of 0.01 metre, requires two cards for one day of data. Corrections for waves above the pressure point are made, where necessary, during reading of the chart, on the basis of trace width as related to wave amplitude during inspections, and in accord with the formula of A5.

On the computer the hourly values are converted to pressure using the gauge calibration factor in Newtons per metre^2 (A1 & A2).

This gauge pressure is converted to pressure at the gas outlet:

Water head pressure above gauge datum = pressure at manometer
- pressure drop due to gas flows(A4 (1))

+ static gas pressure heads (A4(2))
+ non bubbler correction (A6)

The water head above the gauge datum is then calculated using the gravitational acceleration constant and the water density in kilograms per cubic metre (which may be increased linearly with the pressure if desired).

At present three output options are available. Hourly values may be listed together with the correction calculations, and the low and high pass output from the XO tidal filter. This filter separates the diurnal and shorter period tidal constituents from the longer period and non tidal water level changes. Corrected hourly values may also be punched on cards for subsequent harmonic analysis. Finally a plotter routine is available for visual presentation of corrected heights and of the low pass and high pass outputs from the XO filter.

8. Conclusions

Although the manufacturers of the gauge claim an accuracy of 0.01 metres on the 0-3 metres and 0-6 metres ranges, and an accuracy of 0.02 metres on the 0-9 metres, 0-12 metres and 0-18 metres ranges, these accuracies are only possible with certain modifications and with careful use. Also, in the presence of waves or at high bubbling rates, corrections must be made to the gauge readings. The chief source of error is the backlash or lag of the gauge, which appears as a systematic difference between measurements on the rising and falling tide at the same level. To reduce this, it proved necessary to attach a small vibrating motor to the manometer, and to counterbalance the pen; in the presence of waves the pressure fluctuations may have a similar beneficial effect. Another inaccuracy is introduced by density changes in the mercury column equivalent to approximately 0.1% for a temperature change of $5^{o}C$ (Appendix A2) which may only be eliminated by continuous monitoring of mercury temperature.

Apart from the effects of temperature variations, the mercury manometer is a reliable absolute standard and this makes the gauge superior to those which use aneroid capsules for pressure measurement. It must be emphasised that the gauge acts as a pressure balance between a column of water and a column of mercury, and therefore changes in atmospheric pressure above the two columns are not measured. The gauge readings record the pressures due to the water head above the pressure outlet point. I.C.O.T. gauges are calibrated against standard pressures using a deadweight tester as a precaution against incorrect gauge calibration in the factory (which was the case with the gauge under test, possibly because the scaling pulleys were supplied independently of the manometer), and because systematic reduction and correction of readings is easier. If the pressure readings are required for calculation of water level above the outlet datum, then the density of the water must be measured. At Hilbre, to sufficient accuracy, the water density could be expressed as increasing linearly with gauge reading.

For measurements of tidal water level changes around the British Isles, a chart speed of 10 mm. per hour is needed, and for the 0-6 metre range a speed of 20 mm. per hour may be required to be consistent with the accuracy of the water level measurements. Because the timing accuracy is dependent upon the chart drive, the drying agent should be changed regularly; this is also necessary to avoid errors in elevation measurements. Speeds of 20 mm per hour are only possible on battery driven gauges which is unfortunate as battery gauges have a tendency to develop occasional large timing errors. This problem has been put to the manufacturers for their comments.

Generally the gauge has proved easy to install and there is little sign of corrosion after twelve months exposure to the marine environment. For installation on piers or other vertical structures the gauge is much less difficult and expensive than the conventional stilling well; for installation on drying rocks or beaches protection of the connecting tubing is necessary and may be complicated by the short periods of time available for working on low water springs. Where it is not possible to install a continuously falling tube it will be necessary to use a dry air supply, to use a non-evaporating liquid such as glycerol in the bubble sight chamber, and to purge the system periodically.

As a result of these tests extra gauges have been incorporated into the sea level monitoring programme at I.C.O.T. A routine for weekly visits to inspect the gauges has been established: this includes changing the drying agent, checking timing errors, and measuring the temperature and salinity of the seawater so that water elevations may be calculated from the pressure readings of the gauge. Normally the gauge will be used as a bubbling device, but where very long lengths of tube are required, or the air cylinders are inconvenient, the non-bubbling mode may be used to advantage.

An alternative method with very long tube installations is to use two tubes, one for the air flow required for bubbling and one for transmitting the underwater pressure to the manometer (M. Rollet de L'Isle, 1905 - reported by L. Rouḿegoux, International Hydrographic Review Vol. 41, page 111). For a single tube the volume of the gas system increases approximately in proportion to the tube length, so the minimum bubbling rate is correspondingly increased (Appendix A3). Therefore, because the pressure drop along the tube is proportional both to the bubbling rate and to the tube length (Appendix A4), it increases as the square of the length of tube used in the installation, which is why the simple one tube bubbler becomes difficult to use over long distances. Pressure drops due to gas flows along a non-bubbler tube are substantially less, but not zero. The two tube bubbler system would require high bubbling rates which would need frequent changes of gas cylinders, or the use of a compressor motor. Tests of an electrically driven compressor motor at I.C.O.T. were favourable, and the motor vibrations could be used to agitate the manometer; however, the electrical motor could only be used where a mains electricity supply was available.

Pneumatic level measuring systems are potentially very accurate. The accuracy of the Neyrpic gauge is limited by the paper chart recording system, because the paper dimensions change with humidity, and because the location of the drive socket holes may change relative to pen zero. To obtain the accuracy claimed it is necessary to read the records carefully - on the 0-12 metres range 0.01 metres corresponds to 0.25 mm of the chart, which has a width of 0.30 metres.

Significantly larger charts would not be practicable, but more sophisticated recording

techniques are possible. For example, greater resolution should be possible using a stable transducer with electrical output and crystal controlled timing, logging on computer compatible tape, but at considerably greater cost.
The Neyrpic gauge is a well made instrument operating on a simple physical principle. Consequently, providing regular inspections are made, it is capable of obtaining useful reliable and relatively cheap measurements of tidal water elevations.

The work reported here has been carried out at all hours of the day, and in some cases, night, often under extremely arduous conditions, with Mr. D. L. Leighton and the members of his field party; without their industry and resource, particularly when working on the Hilbre installation, these tests would not have been possible.

APPENDIX. SUMMARY OF BUBBLER GAUGE THEORY

A1. Calibration of the gauge

Lateral movement of the gauge pen is related to changes of water level above the pressure outlet by the relationship:-

$$\frac{\Delta N}{\Delta \zeta} = \underset{(1)}{\left(\frac{\rho_{sea}}{r_A}\right)} \underset{(2)}{\left(1 - \frac{A_M}{A_W}\right)} \underset{(3)}{\left(r_B\right)} \underset{(4)}{\left(\frac{1}{\rho_{Hg}}\right)} \qquad \text{------------(A 1:1)}$$

where ΔN is the pen movement,

$\Delta \zeta$ is the change in water level,

and the four gauge factors are as follows:

(1) ρ_{sea} is sea water density and

r_A is the radius of the density pulley.

To keep this term constant the pulley radius is greater for greater water density.

(2) A_M is the cross-sectional area of the manometer float tube and

A_W is the cross-sectional area of the manometer mercury well.

This term accounts for the depression of the mercury level in the well corresponding to a rise of mercury level in the float tube. Accurate adjustment of the gauge sensitivity is made by changing Aw, when the cross-sectional area of the compensatory cylinder (Fig.2) is set to the correct value in the factory. Because of this, sets of manometers and scale and density pulleys should not be changed without recalibration.

(3) r_B is the radius of the scale pulley.

(4) ρ_{Hg} is the mercury density.

Note that for measurements of water elevation the gauge is independent of gravitational acceleration, and that changes of pulley dimensions due to temperature changes cannot affect the sensitivity as the ratio $r_A : r_B$ remains constant.

If the gauge is considered as a pressure measuring instrument:-

$$N_p = K . N \qquad \text{------------(A 1:2)}$$

where Np is the pressure measured on the gauge,

N is the gauge reading

and K is the calibration factor of the gauge.

K is determined experimentally, but from (A 1:1) :-

$$K = \left\{ \frac{1}{r_A} \left(1 - \frac{A_M}{A_W}\right) r_B \frac{1}{\rho_{Hg} . g} \right\}^{-1} \qquad \text{---------------(A 1:3)}$$

where g is gravitational acceleration.

This enables small corrections to be made to K for changes of mercury temperature and, rarely, gravitational accelerations.

A2. Correction of K for temperature effects.

The effect of mercury temperature on K may be determined from (A 1:3) and the relationship between mercury density and temperature. To sufficient accuracy:-

$$\rho_{Hg,T_2} = \rho_{Hg,T_1}\left(1 - 0.000177\,(T_2 - T_1)\right) \qquad \text{-----------(A 2:1)}$$

and hence

$$K_{T_2} = K_{T_1}\left(1 - 0.000177(T_2 - T_1)\right) \qquad \text{-----------(A 2:2)}$$

As an example consider a gauge calibrated accurate at T1 = 20°C, is used at

T2 = 10°C

KT2 = 1.00177 KT1

If this correction is not made the water head calculated from the gauge reading would be lower than the true water head by 0.018 metres for a ten metre water head.

A3. Minimum bubbling rates

Tables of the minimum bubbling rates necessary to accurately follow increases in water level are given in the Neyrpic handbook. These agree closely with the theoretical condition:

$$n_o > \left(\frac{3}{4}\frac{V_o}{\pi c^3}\right)\left(\frac{\Delta\zeta}{10}\right) \qquad \text{------------(A 3:1)}$$

where n_o is the number of bubbles passing through the counter in unit time,

V_o is the total volume of the gas system,

$\Delta\zeta$ is the rate of water rise to be followed, in metres per unit time,

and c is the radius of the bubble counter orifice.

Atmospheric pressure is taken as equivalent to 10 metres of water head.

A4. Pressure drop along the connection tube

(i) Because the pressure drop along the tube is small compared with the absolute pressure, the pressure drop for gas flow is given by

$$\Delta P_t = \left(\frac{8\eta\ell}{\pi a^4}\right)\left(\frac{n}{60}\right)\left(\frac{4\pi c^3}{3}\right) \qquad \text{-----------(A 4:1)}$$

where ℓ is the tube length in metres,

a is the tube internal radius in metres,

n is the number of bubbles per minute,

and η is the viscosity of the gas.

In M.K.S. units η for air varies from 17.1×10^{-6} at 0°C to 18.1×10^{-6} at 20°C.

ΔP_t is in Newtons per square metre.* For normal installations the water head equivalent of ΔP_t is less than 0.01 metres.

(ii) Because of the static pressure heads of gas in the connecting tube and in the atmosphere, a further composite correction must be added to the gauge pressure:

$$1.29\; g \left(\frac{H}{10} + 1\right)\zeta \qquad \text{-----------(A 4:2)}$$

where 1.29 is the density of air in Kg/M^3 at S.T.P.,

g is gravitational acceleration,

H is the height of the gauge about the outlet level in metres,

and ζ is the instantaneous water elevation.

For H = 10 metres, ζ = 10 metres the correction is equivalent to 0.025 metres of water head.

* 10^5 Newtons per square metre = 1 Bar = 14.50 p.s.i.

A5. Response of a bubbler system to waves

The bubbling rate of a gauge is normally set sufficiently high to follow tidal changes of water level without water forcing its way into the system, but it is then about two orders of magnitude too low to follow changes of water level due to waves. Therefore, the bubbler system behaves as a constant gas mass system when responding to waves.

The difference between the average sea level and the level recorded on the chart is:-

$$\left(\frac{V_0}{A_0}\right)\left(\frac{\Delta P_w}{P_0}\right) \qquad \text{for } \frac{\Delta P_w}{P_0} \ll 1 \qquad \text{----------(A5:1)}$$

where A_0 is the horizontal cross-sectional area of the pressure point outlet,

ΔP_w is the pressure amplitude of the waves at the outlet,

and P_0 is the pressure in the trough of the waves.

The average gauge reading is lower than the average sea level by this amount.

Using length units instead of pressure, we have, approximately:-

$$\left(\frac{V_0}{A_0}\right)\left(\frac{\Delta h}{H_0 + H_A}\right) \qquad \text{-----------(A5:2)}$$

where H_0 is the water level in the trough of the wave,

H_A is the water level equivalent to atmospheric pressure,

and Δh is the wave amplitude.

If there is no damping in the pressure transfer to the measuring device, then Δh may be estimated as half the trace width. H_0 is the level to the bottom of the trace, and H_A is 10 metres with sufficient accuracy for the calculation of the correction. If there is damping in the pressure system, then the wave amplitude must be estimated by some other means. Note that this is a length correction, independent of water density, and so it is best made by adding to the elevations calculated from the gauge reading.

It is important to make (V_0/A_0) as small as possible, and so the pressure point outlet is designed to have a large value of A_0. For 100 metres of tubing of internal radius 2 mm, and the Neyrpic tidal pressure point, (V_0/A_0) is approximately 0.30 metres. For a wave of amplitude 1 metre, on a mean water level of 5 metres, the correction to be added is:

$$0.30 \quad \frac{1}{(15)} = 0.02 \text{ metres}$$

The open end of the tubing should never be used as the underwater outlet, as Ao becomes very small, and the errors correspondingly large.

A6. The non-bubbling gauge

If bubbling is stopped, then the gauge behaves as a constant mass system for tidal water level changes, as for wave level changes. However, (A5:1) is not sufficiently accurate as $(\Delta P_w/P_0)$ is no longer small. The water level pressure, Pt, is related to the measured water level pressure, Pg,:

$$P_t - P_g = (g\,\rho_{sea})\left(\frac{V_0}{A_0}\right)\left(1 - \frac{P_0}{P_g}\right) \qquad \text{------------(A6:1)}$$

where Po is the pressure when gas is on the point of escaping from the system, i.e. at volume Vo.

If the system is inflated periodically, then Po is the pressure at inflation. If the water level falls below the gas outlet, and then rises above it, then Po is the atmospheric pressure when the water re-enters the system. In units of length, the gauge reads low by:-

$$\left(\frac{P_t - P_g}{g\,\rho_{sea}}\right) = \left(\frac{V_o}{A_o}\right)\left(1 - \frac{H_A + H_I}{H_A + H_G}\right)$$

where H_I is the water level corresponding to H_o ,

H_G is the water elevation measured by the gauge,

and H_A is the atmospheric pressure water head equivalent,

as previously.

All the terms on the right of the relationship may be determined, and the correction applied. Alternatively the system may be calibrated against a tide pole. This gauge is similar to the partially-inflated tyre type of pressure gauge, but datum is much better determined. As an example, for a five gallon oil drum, (V_o/A_o) is approximately 0.40 metres, and so the correction to be added to the gauge reading at H_G = 5 metres and H_I = 0 metres is:

$$0.40 \left(1 - \frac{10}{10 + 5}\right) = 0.133 \text{ metres.}$$

A7. Routine Inspection Procedures

A copy of the standard inspection form and of the explanatory notes is included at the end of the report.

Appendix 7 COPY OF:

NOTES FOR THE GUIDANCE OF NEYRPIC GAUGE INSPECTORS

Introduction

These notes are intended for ICOT personnel making routine inspections of Neyrpic bubbler gauge installations. All inspections should be reported on the standard form which outlines a series of observations designed to thoroughly check that the gauge is correctly recording water pressures. Please complete the various parts of the form sequentially as the order is important. These notes explain how these various parts of the form should be completed.

A regular and systematic check should be made once a week. Provided that nothing is seriously wrong, an inspection should not take more than an hour; however, a complete and careful inspection, even of a perfectly running gauge, will take at least half an hour.

Note that this routine is not to be used for non-bubbler installations.

Before leaving ICOT

Complete section A of the form by reading through the report of the previous inspection, and note any action recommended for this visit.

Inspection numbers run sequentially, from one, for each installation.

Chart range, bubbling rate and gas supply low pressure are all constants for a particular installation. The check standard may be either a tide pole or some reliable nearby conventional gauge, against which the Neyrpic level is compared. Because the accuracy with which the standard may be read depends upon the conditions (particularly for a tide pole in the presence of waves), the standard difference is only a guide to the acceptable difference between the readings of the standard and the Neyrpic.

Check the watch or chronometer against a time standard, either radio signals or TIM.

Collect a fresh vibrator motor battery (where applicable) and fresh drying agent, and take the box of spares and servicing tools.

SECTION B.

The information in this section is needed for relating features on the record to environmental conditions.

Time of arrival at gauge:- all times should be given to the nearest minute and the time zone (G.M.T. unless special instructions are given) specified.

In attendance:- please list all the people present.

Weather conditions, wind:- give the wind speed and direction and a general description of the precipitation (e.g. drizzle, raining etc.).

State of tide:- when other people are reading through a form upon return to ICOT, and if the record from the gauge is not available, it is useful to know the state of the tide at the time of inspection relative to the time of the previous high or low water on the Neyrpic chart.

Peak to trough wave height:- this information, which should relate to the waves above the pressure point installation, is needed to calculate a correction factor for the gauge. If it is not possible to observe waves immediately over the pressure point, measure as closely as is practicable, and make a note to this effect on the form. Measurement will be particularly difficult where a pressure point is installed well off shore. All measurements should be in metres (e.g. 7 cms. is 0.07 metres).

Estimated currents:- as above, this may be difficult for off shore pressure point installations, but relatively easy under a pier or alongside a harbour wall. (1 knot = 0.515 metres per second, or, to sufficient accuracy, 2 knots = 1 metre per second).

Sea water sample:- measure the temperature and salinity of a sample of sea water taken from as near the pressure point as is practicable. Use the Electronic Switchgear bridge, and read temperature to 0.1°C, and salinity to 0.1 ppt. (A bucket sample is better, but direct immersion of the sensor in the sea is acceptable). Note the number of the bridge used. The sea water density is needed to convert the gauge reading to true water height above the pressure point, and so upon returning to ICOT, correct both the temperature and salinity readings using the latest calibration data, and then work out the equivalent water density from the temperature and salinity curves for σt. (Density = $(1000 + \sigma t)$ $Kg/metre^3$).

State of piping and pressure point where visible:- please carry out this inspection carefully and do not leave until any defects have been sufficiently repaired to last until the next visit. Note any action necessary for the next visit at the foot of the form.

SECTION C

It is particularly important that the tests in this section are made in the order indicated.

Condition of vibrator:- where fitted, the vibrating motor attached to the manometer serves to reduce the gauge lag due to the float and pulleys sticking. If the manometer is felt to vibrate slightly by finger touch, then the vibration is satisfactory.

Air temperature next to manometer:- because the gauge is a pressure balance, a correction is necessary to allow for the effects of temperature changes on the mercury density. Use the Electronic Switchgear bridge and measure to an accuracy of 0.1°C. This reading will need correcting, for bridge calibration, upon return to ICOT. Because the thermistor at the end of the bridge sensing head will have been wetted during measurements on the sea water sample, please dry the thermistor before measuring the air temperature, to avoid errors due to evaporative cooling.

Paper drive conditions:- cross out all but the correct descriptions, and make any additional observations necessary. Action is necessary if the paper is not taut and square (see below).

Trace conditions:- unsatisfactory conditions include sudden jerks in elevation or time, flats at high and low water, ink running or too faint. Please make a note of wave motions and amplitudes on the chart at the time of observation, and note any unusual wave activity showing on the visible part of the record.

Check of Neyrpic against standard:- make three pairs of simultaneous readings of the Neyrpic and of the local standard. The local standard may be a tide pole or another gauge; details will have been entered under Section A before leaving ICOT.

Note the time of the separate readings as this gives an indication of the rate of change of level during the visit, and may be used to check the consistency of the readings. Take the means of the two sets of readings, convert the standard to metres if necessary, and difference them. Please work out the results and be sure that they are satisfactory before leaving the gauge, as the purpose of this test is to detect conditions which require attention. The standard difference noted in Section A is to be used as a guide, but if the value obtained is anomalous, an explanation is necessary. In some conditions anomalies may be due to difficulties in reading the standard - for example a tide pole in rough seas may only be readable to within 0.30 metres, whereas in calm conditions reading may be possible to within 0.01 metres.

*** Disconnect pressure line:- by releasing the snap fastener on the left side of the gauge. Mark the date and inspection number on the chart, but be careful not to move the paper when doing so. If the paper is not riding properly in the guide sprockets, the timing lines will not be parallel to the pen track. Please make a note if this happens. Where wave filters are fitted some minutes might be needed before the pen reaches zero.

Chart zero at:- the pen zero is always read after the pen has approached it from the right (higher pressure). When resetting zero it is necessary to check the setting by increasing the pressure slightly and letting it fall back to zero, or by raising and lowering the float in the manometer slightly. The pen zero should be reset if it differs by 0.01 metres or more from chart zero.

Timing mark:- when the pen reaches zero and the zero level has been checked, make a timing mark by moving the pen slightly with its drive pulley. Note the true time and the chart time when this mark is made.

Chart fast/slow by:- work out the gain or loss of the chart since the previous visit before leaving the gauge as corrective measures may be necessary. The gain or loss should be less than 1 minute per day otherwise an explanation is required, and regulation may be necessary.

Bubbling rate:- is measured by counting in the glass sight chamber. A count of 30 second doubled is sufficiently accurate, and should be expressed as bubbles per minute. The bubbling rate for an installation depends upon the tube length and the maximum rates of water level rise to be measured, and will be decided at installation. If the rate measured differs by more than 10% from the rate specified in Section A, adjust it by rotating the small brass nut above the sight chamber. Note that this bubbling rate should always be measured with the pressure point disconnected.

Record removed:- for weekly inspections the record should be removed on alternative visits as records should be inspected in the laboratory at this interval. A record of two weeks length is easy to handle but longer records are inconvenient.

Adjustment (or refitting) of chart:-

(a) if the paper drive is unsatisfactory

(b) if the timing is wrong by more than five minutes

It is necessary to remove the take up roll and retension it, making sure that it is evenly wound so that the chart lies flat over the chart table. One of the unsatisfactory features of the Neyrpic is that any adjustment of the chart causes a delay before paper drive takes up. For the first model supplied to ICOT the delay is 8-10 minutes with the paper set against the backlash, so it is necessary to anticipate this delay when resetting the paper. To do this, once the paper is fitted, wind it on until it is about 20 minutes fast relative to G.M.T. and then wind back until it is 10 minutes fast. Once the paper drive has taken up it will be necessary to make a fresh timing mark on the chart by moving the pen on the zero line.

Resetting of zero:- necessary if chart and pen zero differ by 0.01 metres or more (see above).

Resetting bubbling rate:- necessary of rate differs from that noted in Section A by more than 10%.

Purge: only purge the line if it is thought that a blockage may exist from the evidence of trace irregularities or discrepancies between the readings of the Neyrpic and the local standard (which will have been noted earlier in the inspection). To purge, connect the pressure line to the purge connector outlet (above the pressure point connection outlet), fully open the red knob of the valve control by turning it anti-clockwise, and allow air to flow for one minute. Further purging should not be necessary if the gauge and the standard now give satisfactory agreement. If not, repeat the purge for a second minute. Further discrepancy will require a more careful examination of the system.

*** Reconnect the pressure line to its normal outlet:- if the line has been purged wait for a minute for the tube pressure to fall before reconnecting the pressure line.

Gas supply:-

(a) the high pressure should normally be at least 30 bars for there to be enough gas to last until the next visit. If it is less than this, change the cylinder.

(b) the low pressure is set at the beginning of operating the installation. If it is different from the pressure noted in Section A by more than 10%, adjust it by means of the reduction valve.

Ink reservoir:- do not overfill as this increases friction between the pen and the paper.

Connect new battery:- where a vibrator motor is used, a newly charged 12 volt, 40 AH, battery should be fitted weekly.

Change drying agent:- this must be done weekly. Poor drying agent may result in damp distorted charts, and may contribute to timing errors.

Rewind/Battery:- for battery operated gauges, check that the battery expiry date has not elapsed. A life time of two months is allowed for each battery. If a new battery is needed, fit it in the container and mark it with the expiry date. (SP2 or U2 cells - 1.5v - are used). For clockwork gauges, wind up weekly.

SECTION D.

This space is for observations not included elsewhere on the form, or for expansion of points for which insufficient space was available. Please be careful to complete the section on actions for the next visit, otherwise they may be forgotten until the next inspection is made, which may be too late if extra equipment is needed. Do not rely on memory!

Note the time of leaving the gauge.

<u>On return to ICOT</u>

It is best to make immediate arrangements for recharging used drying agent and batteries.

Correct the Electronic Switchgear bridge readings of temperature and salinity (* on form) and compute the corresponding water density.

Finally give the completed forms to Mr. Leighton for checking and forwarding to Project 1:1 for analysis.

SPECIMEN FORM.

INSPECTION OF NEYRPIC BUBBLER GAUGE INSTALLED AT:- Hilbre Island.

SECTION A. Preliminary

INSPECTION NUMBER: 7

DATE: 12/10/71

Chart range: 0-12 metres.

Check standard: Légé

Standard difference: 0·15 metres

Bubble rate: 60/minute.

Gas low pressure: 3 bars.

On inspection No....6........the chart was 3 mins. fast/~~slow~~ at..1506....GMT.

Watch/~~chronometer~~ checked against Tim/~~radio~~ at 1003 GMT

SECTION B. General

Time of arrival at gauge: 1400 GMT

In attendance: A.B. & CJW

Weather conditions, wind: 3-5 N.E. Cold; raining

State of tide: 2½ hours after high/~~low~~ water at 7·16 metres on Neyrpic.

Estimated peak to trough wave height above pressure point: 0·4 metres.

Estimated currents above pressure point: 0·5 metres per second.

Sea water sample from near pressure point temperature 11·7 °c; salinity 34·1 ppt

Bridge Number: *corrected 11·8 °c; *corrected 34·0 ppt

(*to be completed at ICOT) *density 1025·9 kg/M3

State of piping and pressure point installation where visible:

Conduit piping loose below second walkway. Temporary repair made

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SECTION C. Gauge

Condition of vibrator:- ~~strong~~/satisfactory/~~weak~~/~~stopped~~
(where applicable)

Air temperature next to manometer: 14·3 °c *corrected 14·4 °c

Paper drive condition: sprocket holes - fitting/~~slightly out~~/~~mangled~~;
square/~~slightly skew~~/~~skew~~;
smooth/~~slightly wrinkled~~/~~wrinkled~~;
dry/~~damp~~/~~very damp~~

Trace condition: Smooth/~~jerky~~/~~flats at High, Low water~~; ~~faint~~/clear/~~smudged~~;
wave motions showing/~~not showing~~; amplitude on chart; 0·05 metres.

Elevation check:

	Neyrpic reading	Standard	Time (GMT)
1	3·13 M.	2·97	1421
2	3·11	2·95	1423
3	3·10	2·90	1424
means:-	3·11	2·94	

Neyrpic - Standard = 0·17 metres satisfactory/~~unsatisfactory~~.

*** Disconnect pressure line - mark date and inspection number on chart

- when pen reaches zero make a timing mark by moving pen.

Chart zero at: 0·01 metres

True time of mark 1426 GMT
Chart time of mark 1425 GMT (on zero line)
Chart ~~fast~~/slow by :- 1 minutes
Chart ~~gain~~/loss since previous visit is 4 minutes
Chart ~~gain~~/loss is 4 minutes in 8 days
Chart ~~gain~~/loss is 0·5 minutes per day

Bubbling rate: 61 bubbles per minute

Record removed (approximately every two weeks) Yes/~~No~~

Fit new chart or adjust old chart for timing and alignment errors if necessary:

- make new time mark on zero line
- mark date and inspection number if a new chart fitted.

Chart now fast/~~slow~~ by 2 minutes at: 1445 GMT

Zero reset to 0·00 metres (pen approaching from higher pressure)

Bubbling rate adjusted to: left.

Purge:- No/~~Yes;~~ for minutes

*** Reconnect pressure line.

Gas supply high pressure: 65 Bars Low pressure: 3 Bars

Ink reservoir: ~~full~~/half/~~empty~~ (half full is adequate)

Connect new vibrator motor battery: ✓
(where applicable)

Change drying agent ✓

~~Clockwork rewind~~/battery check: o.k.

SECTION D.

Other action taken:

Comments: Unusual swell on trace at previous high water

Action for next visit: New rewind battery required next week.

Time of leaving gauge 1455 GMT

(Signed) ....A. Brown....

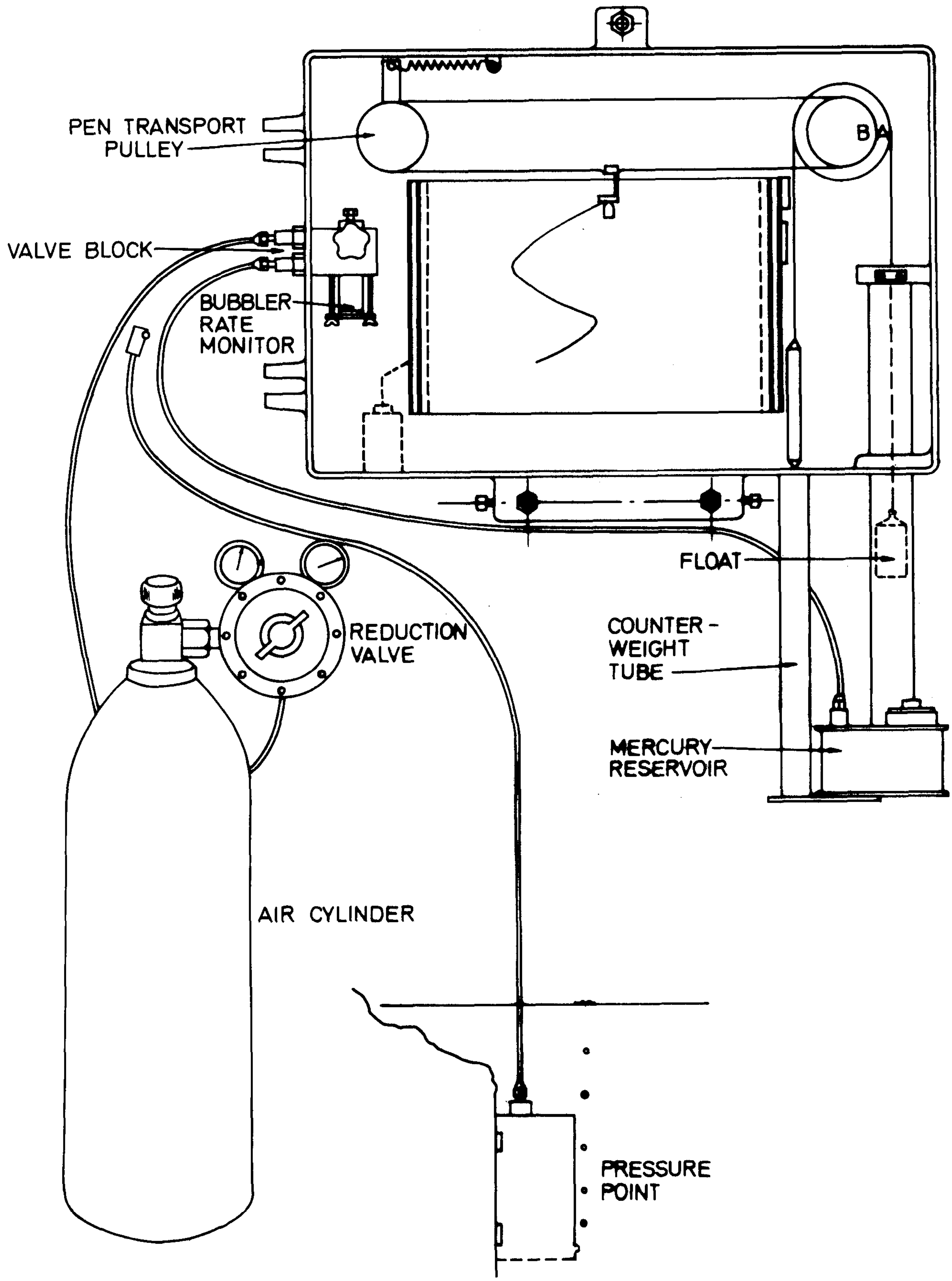

FIG. I : DIAGRAM OF NEYRPIC BUBBLER GAUGE

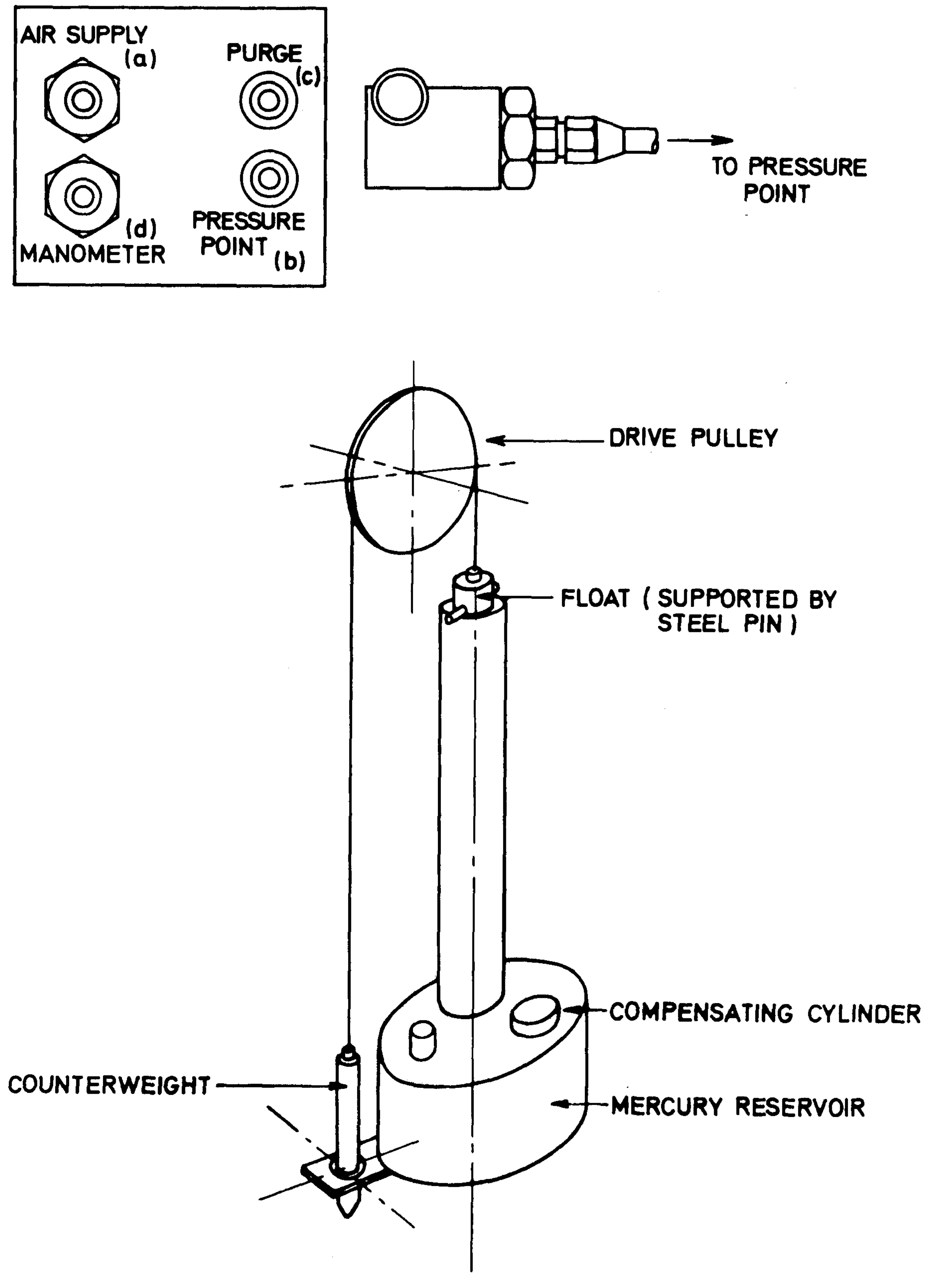

FIG 2 CONNECTIONS TO THE VALVE BLOCK, AND THE FLOAT COUNTERWEIGHT SYSTEM

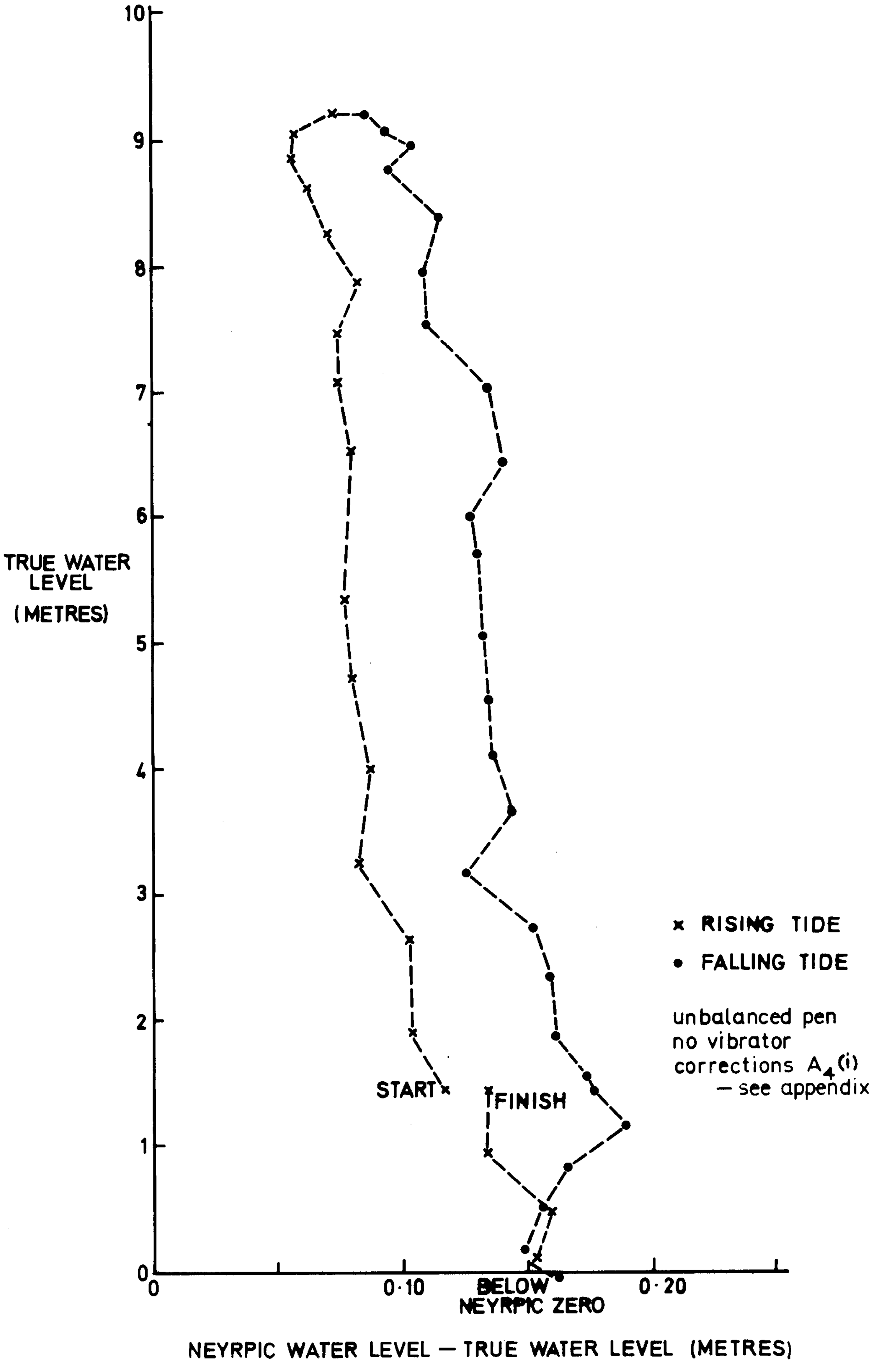

FIG. 3. VAN DE CASTEELE PLOT OF BUBBLER GAUGE ERRORS IN ALFRED DOCK STILLING WELL — 6th. APRIL 1970

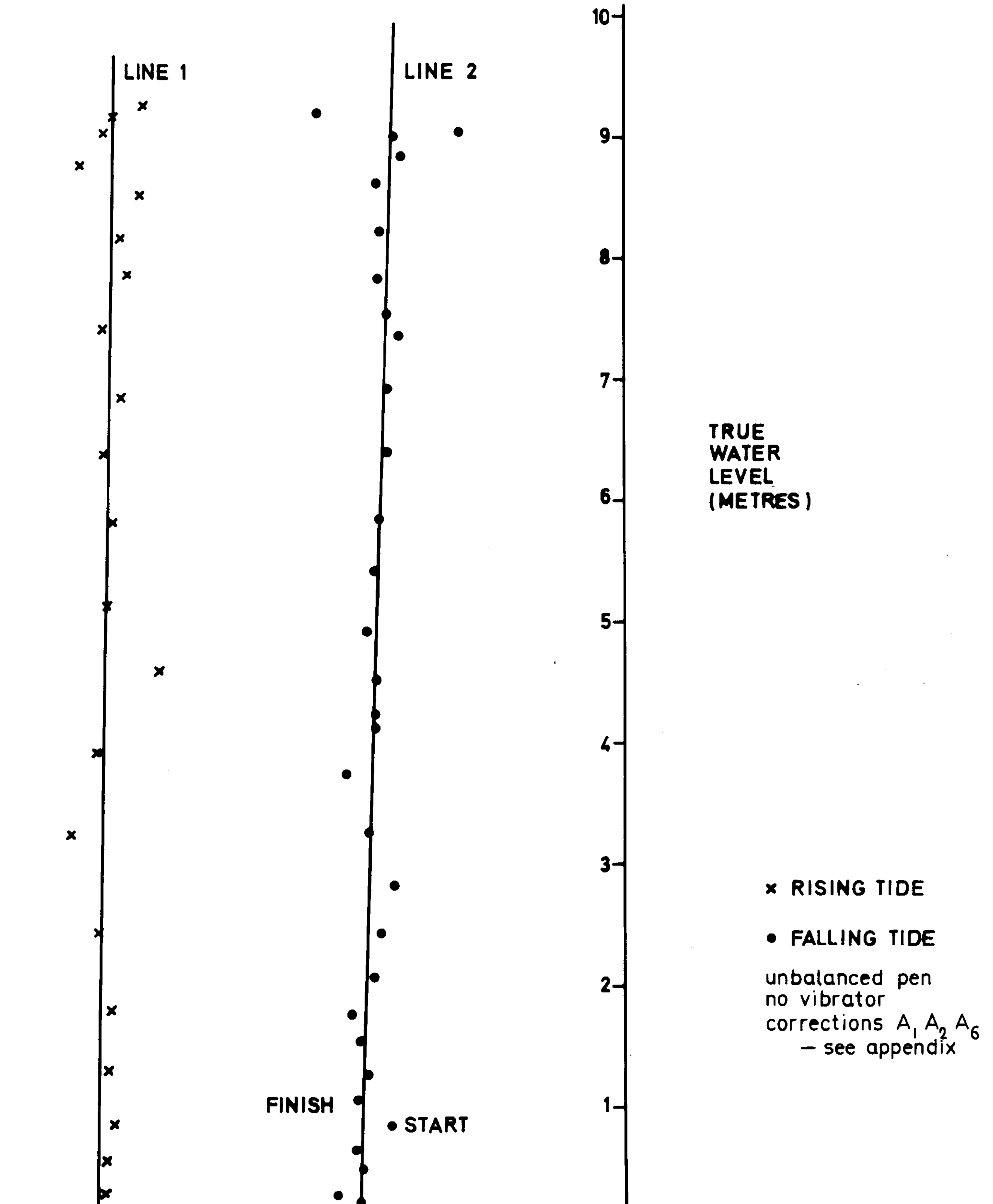

FIG. 4. VAN DE CASTEELE PLOT OF NON - BUBBLER GAUGE ERRORS
ALFRED DOCK STILLING WELL — 11th. MARCH, 1970

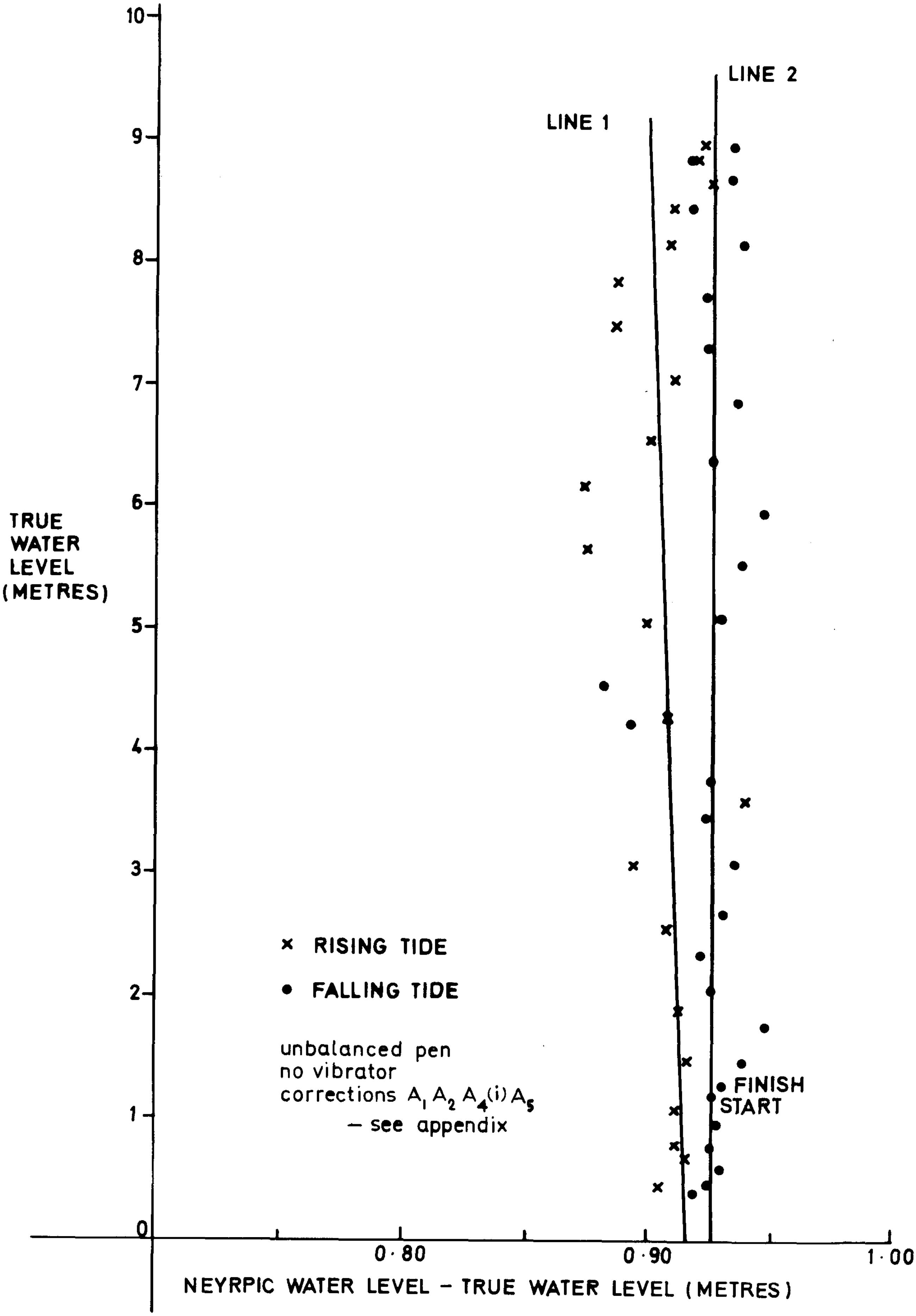

FIG. 5 VAN DE CASTEELE PLOT OF THE DIFFERENCE BETWEEN BUBBLER GAUGE READINGS IN THE RIVER MERSEY, AND WATER LEVELS IN THE ALFRED DOCK STILLING WELL – 9th. APRIL, 1970

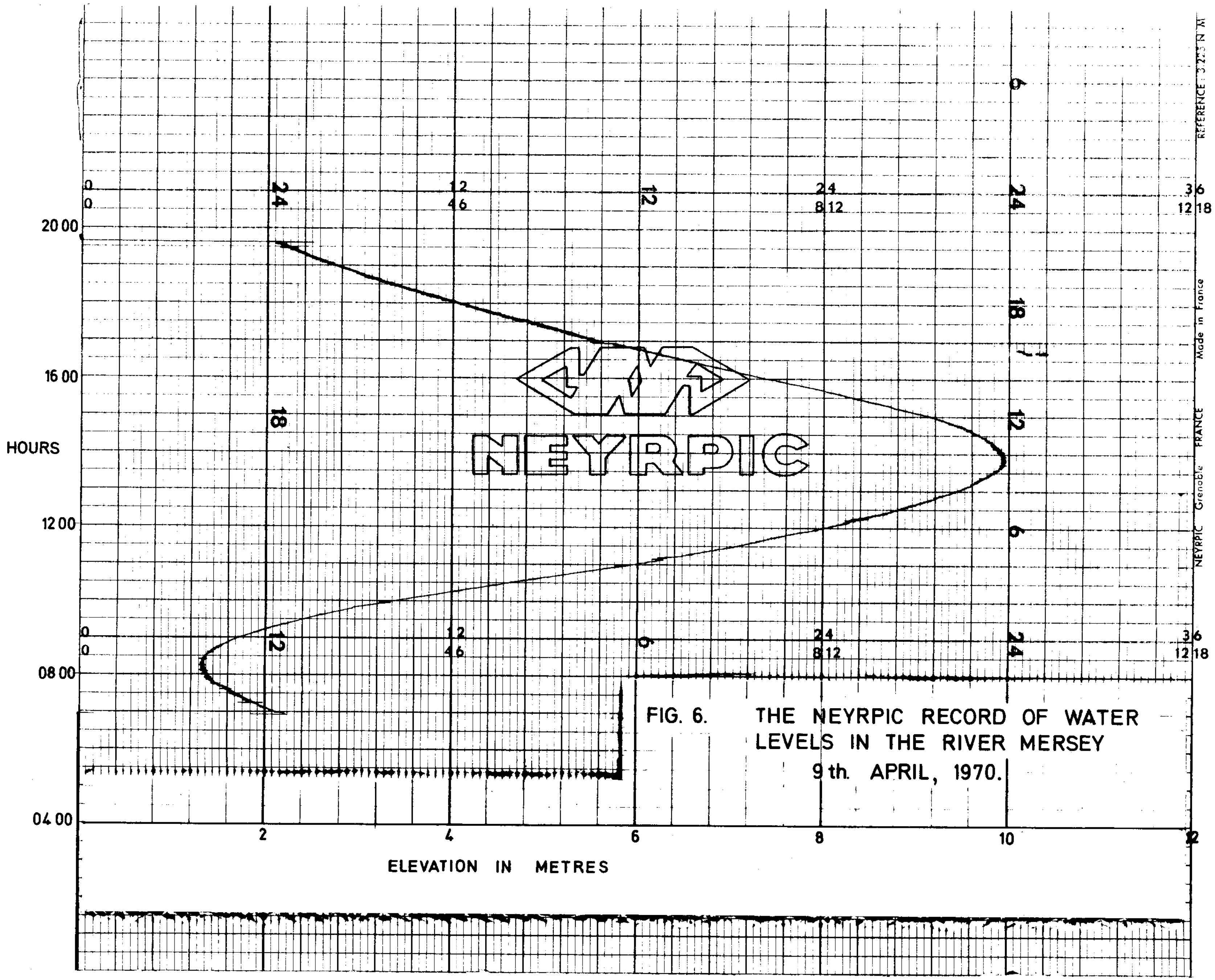

FIG. 6. THE NEYRPIC RECORD OF WATER LEVELS IN THE RIVER MERSEY 9th. APRIL, 1970.

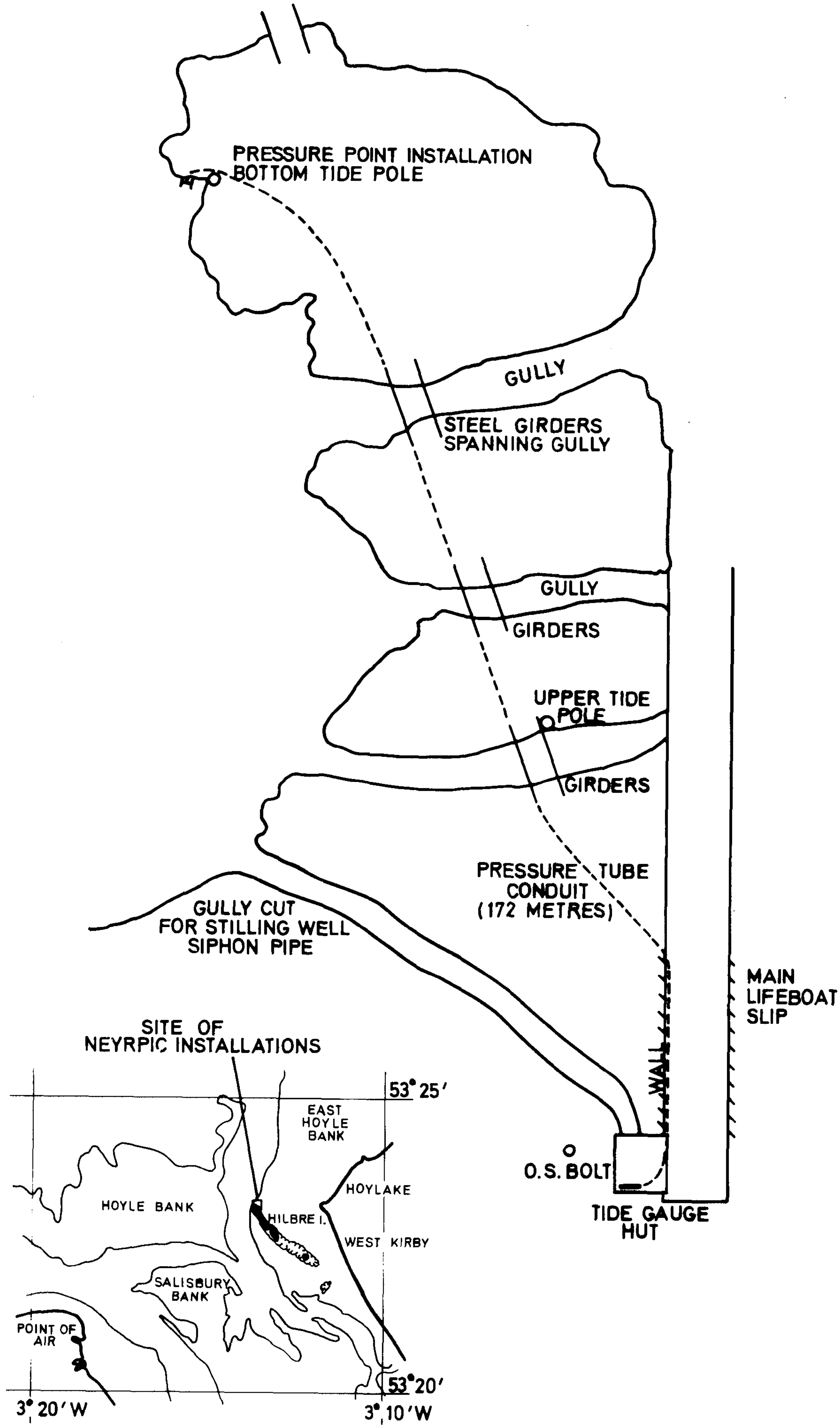

FIG. 7 SKETCH MAPS SHOWING POSITION OF NEYRPIC INSTALLATIONS ON HILBRE ISLAND

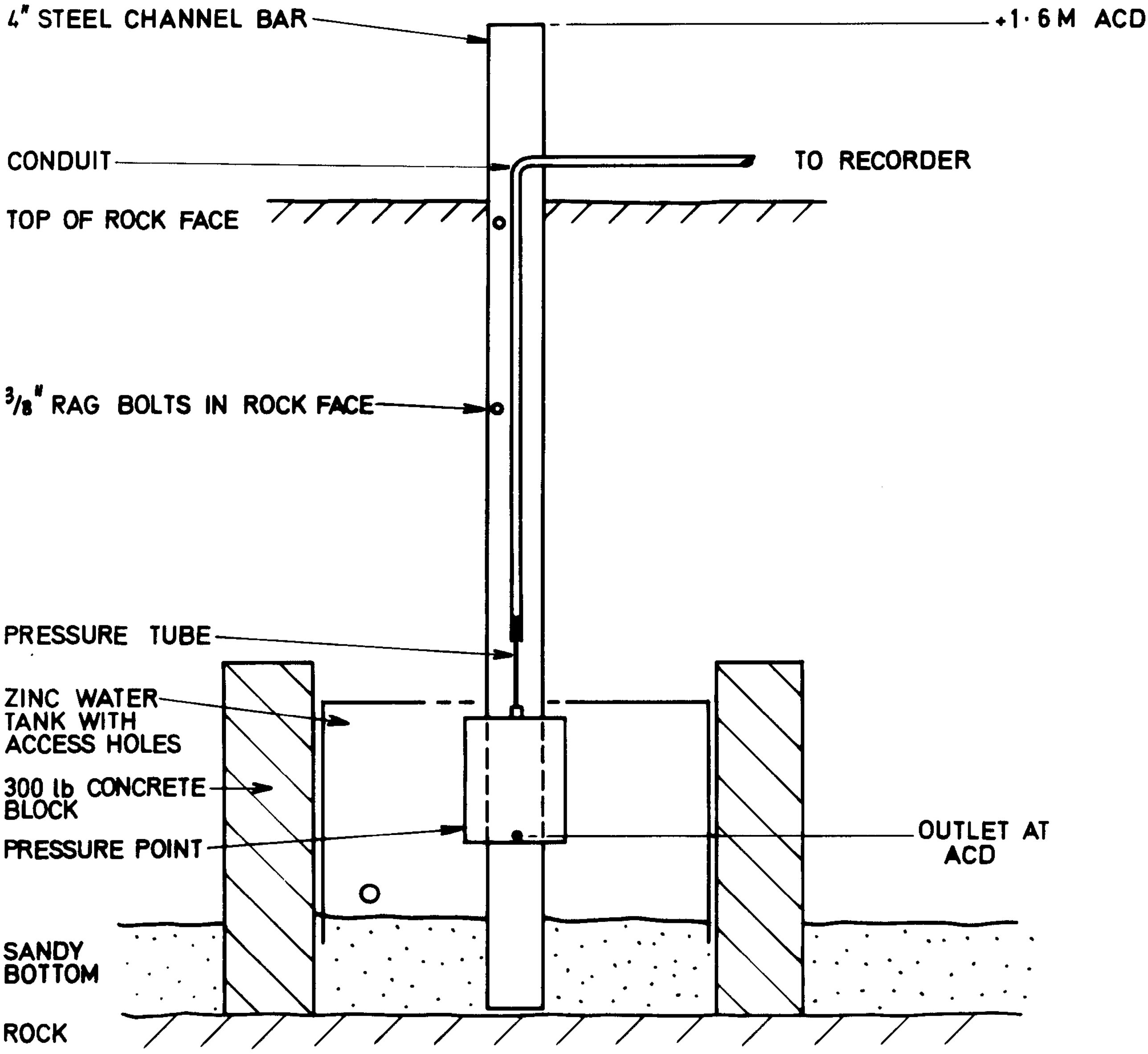

FIG. 8. DETAILS OF PRESSURE POINT INSTALLATION AT HILBRE

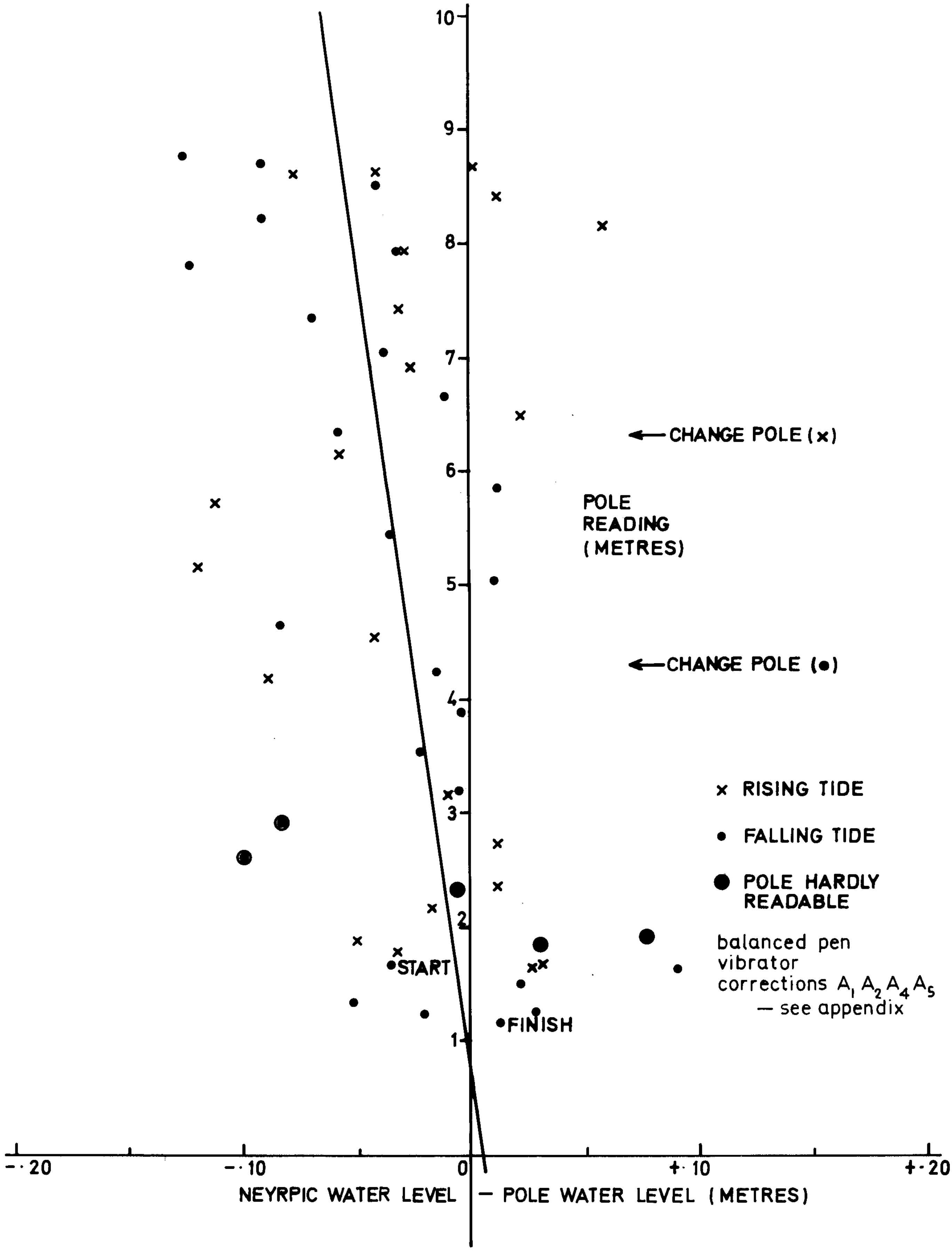

FIG. 9 VAN DE CASTEELE PLOT OF BUBBLER GAUGE READING COMPARED WITH TIDE POLE READINGS AT HILBRE 16th. NOVEMBER, 1970

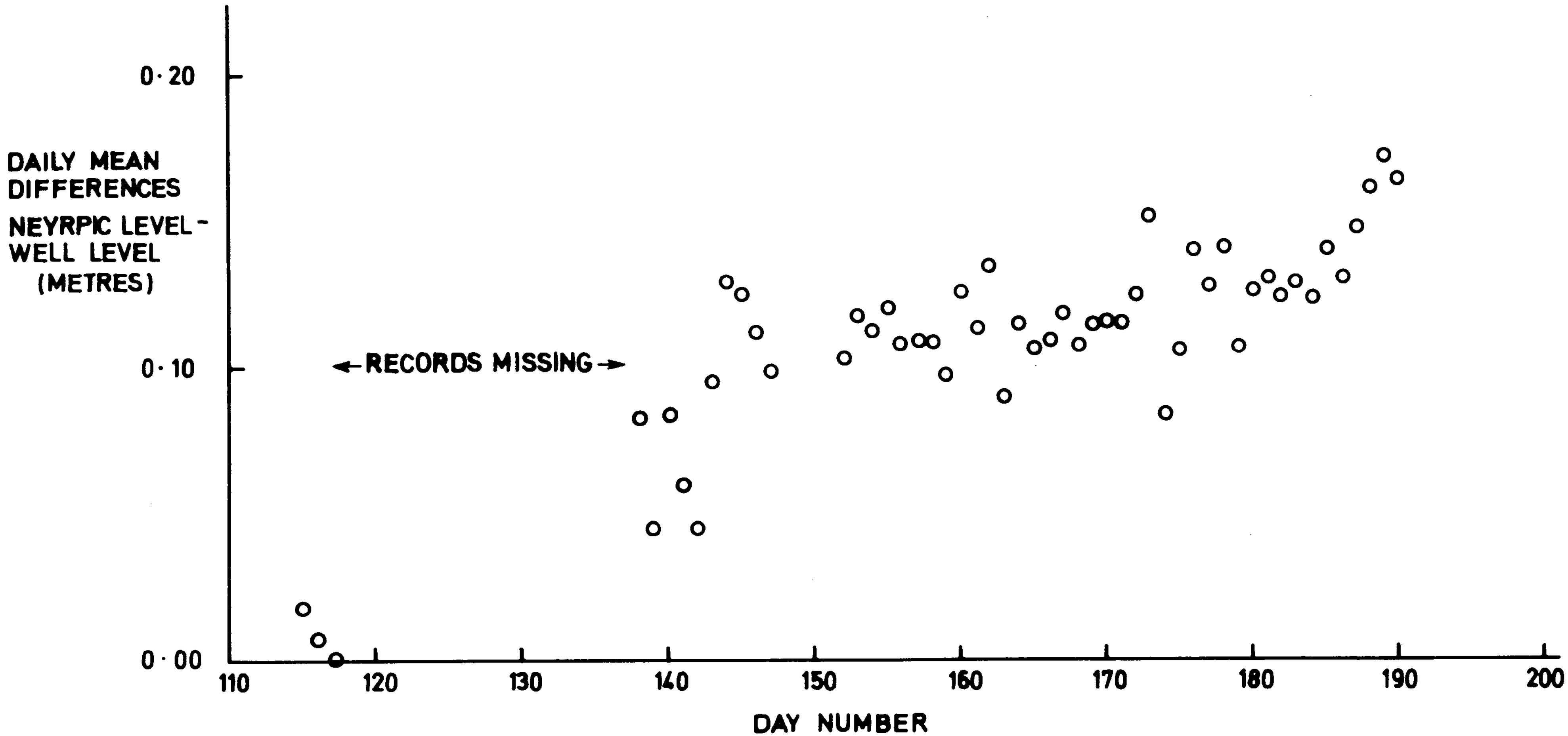

FIG. 10 NON BUBBLER DATUM DRIFT AT HILBRE ISLAND. APRIL-JULY. 1971. COMPARED WITH WELL LEGE.

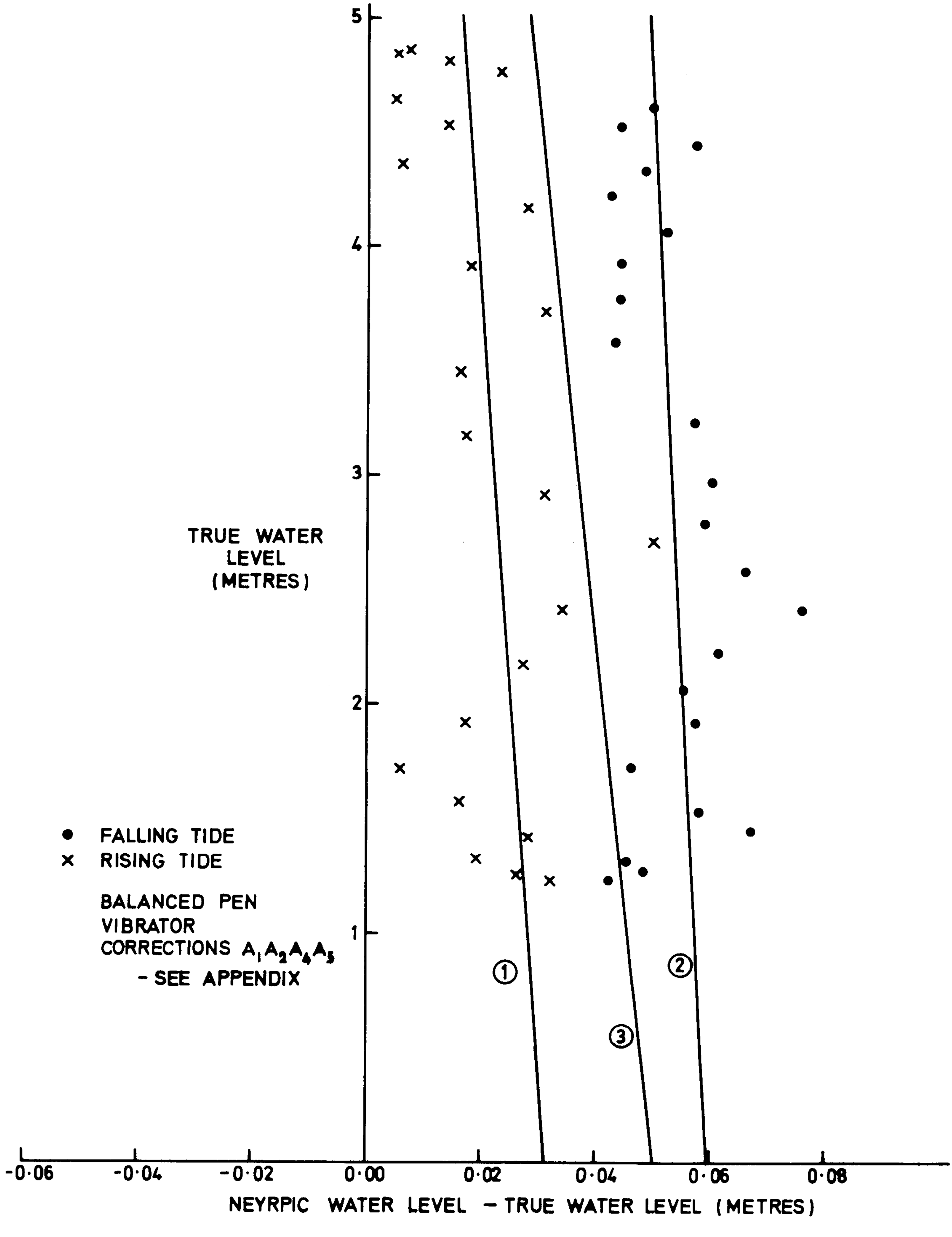

FIG. 11. VAN DE CASTEELE PLOT OF BUBBLER GAUGE ERRORS AT NEFYN 21st SEPTEMBER 1971

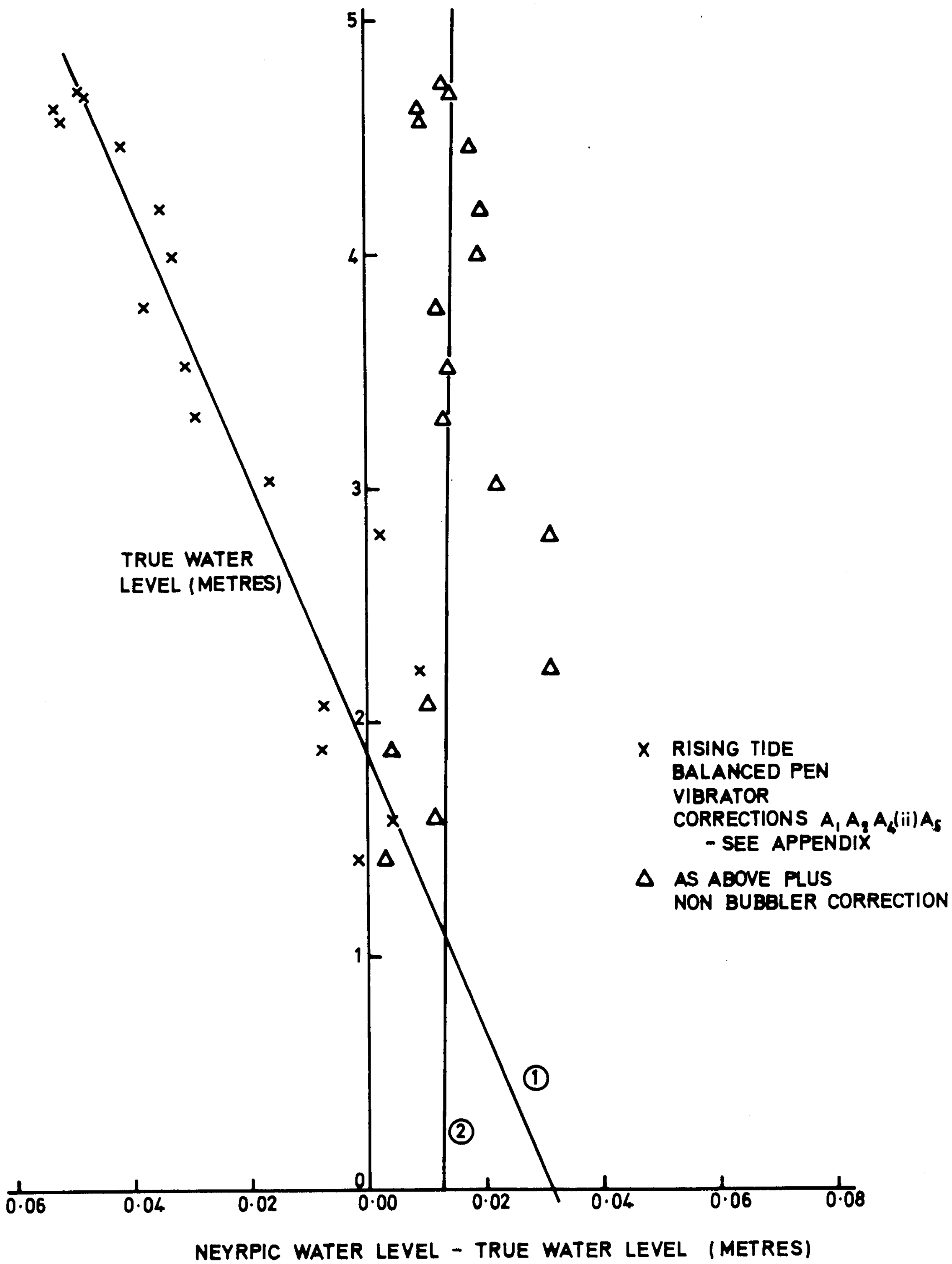

FIG. 12. VAN DE CASTEELE PLOT OF NON BUBBLER GAUGE ERRORS AT NEFYN (RISING TIDE ONLY) - 22nd SEPT. 1971