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NOTES TECHNIQUES

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THE EVALUATION OF TIDE GAUGE PERFORMANCE THROUGH THE VAN DE CASTEELE TEST

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The rate of progress of the geophysical sciences depends upon the ability of the numerical analyst to take full advantage of the quality of observations which the instrument engineer is able to provide. Perhaps more important in the present context, progress also depends upon the ability of the engineer to provide data of a quality to match the available numerical techniques. In this sense it is vital that developments in these two branches of applied science should be compatible. In practice, experience has shown that the two disciplines tend to proceed independently so that at any point in time a marked imbalance exists. In tidal science, for example, it can be said that in the period upto the mid nineteen fifties the analyst, struggling with manual techniques, was striving to realise the full potential of the traditional tide gauge records. After this date the advent of the electronic computer gave a distinct advantage to the analyst and at present it can be seen that in many countries the analyst has learned to use his new tool to great advantage. In his work a question is arising with increasing frequency : are the phenomena under investigation wholly real or do they contain significant instrumental contributions ? In many cases the answer is far from certain.

Inadequacies of Conventional Instrumentation

Concern over the performance of the conventional tide gauge installations has been mounting over recent years. There are many common faults, some arising from inadequacies in design and others from careless maintenance. The analogue gauge which produces an ink trace upon a paper chart fixed to a rotating drum, is particularly prone to error. Invariably a stilling-well is used to effect a damping of surface waves. Anomalous pressure patterns may arise, due to local obstructions of streams, which are transmitted via the orifice to produce erroneous levels within the well. Periodic changes of water density in the vicinity will imply that the water sample contained within the well is not of comparable density with that of the open water, particularly at high water. In the Mersey estuary this condition has been shown to account for positive anomalies of well levels of 6 cm magnitude. Again the accumulation of sediment and marine growth at the base of the well, and especially in the orifice, can impair operation and may seriously change the response characteristics of the stilling system so as to distort the tidal oscillations. The above faults are inherent in the choice of site and in the use of a stilling well system. Once encountered, very little can be done to improve performance, other than to keep the errors due to silt and organic growth to a minimum by frequent cleansing operations. However, many other faults occur, particularly in the ability of the recording mechanism to sense accurately the water level present in the well. The following list contains some common faults which arise in this context :

- mechanical friction
- blacklash in gearing
- damaged gears
- riding turns in float suspension, counterpoise suspension or pen carriage drive
- errors in chart graticule arising from manually drawn printing blocks
- errors in chart graticule arising from himidity changes
- obstructions to free movement of float or counterweight
- misaligned, or eccentric recording drum
- float dimensions incompatible with mechanical load.

In these cases it is often possible to effect improvement if there is available a rigorous process capable of sensing the presence of a fault and, better still, of diagnosing the cause. The significance of this fact was most apparent in the U.K. where the network of tide gauges used to monitor sea elevations, is mainly in the hands of local authorities which are responsible for day to day maintenance. In view of this situation the Tidal Institute was most interested in the original contribution made by Mr. Charles Van de Casteele to the Oceanographic Section of the French National Committee of Geodesy and Geophysics in June 1962, since published in Cahiers Oceanographiques XX, 1 (janvier 1968). In the above context, the potential of the check which Mr. Van de Casteele introduced was realised and in consequence a series of experiments was undertaken at the Institute.

THE VAN DE CASTEELE TEST

Probe

In order to test the ability of a tide gauge to record water levels, it is desirable to have the instrumental means to measure water levels independently with an accuracy one order higher than the required performance of

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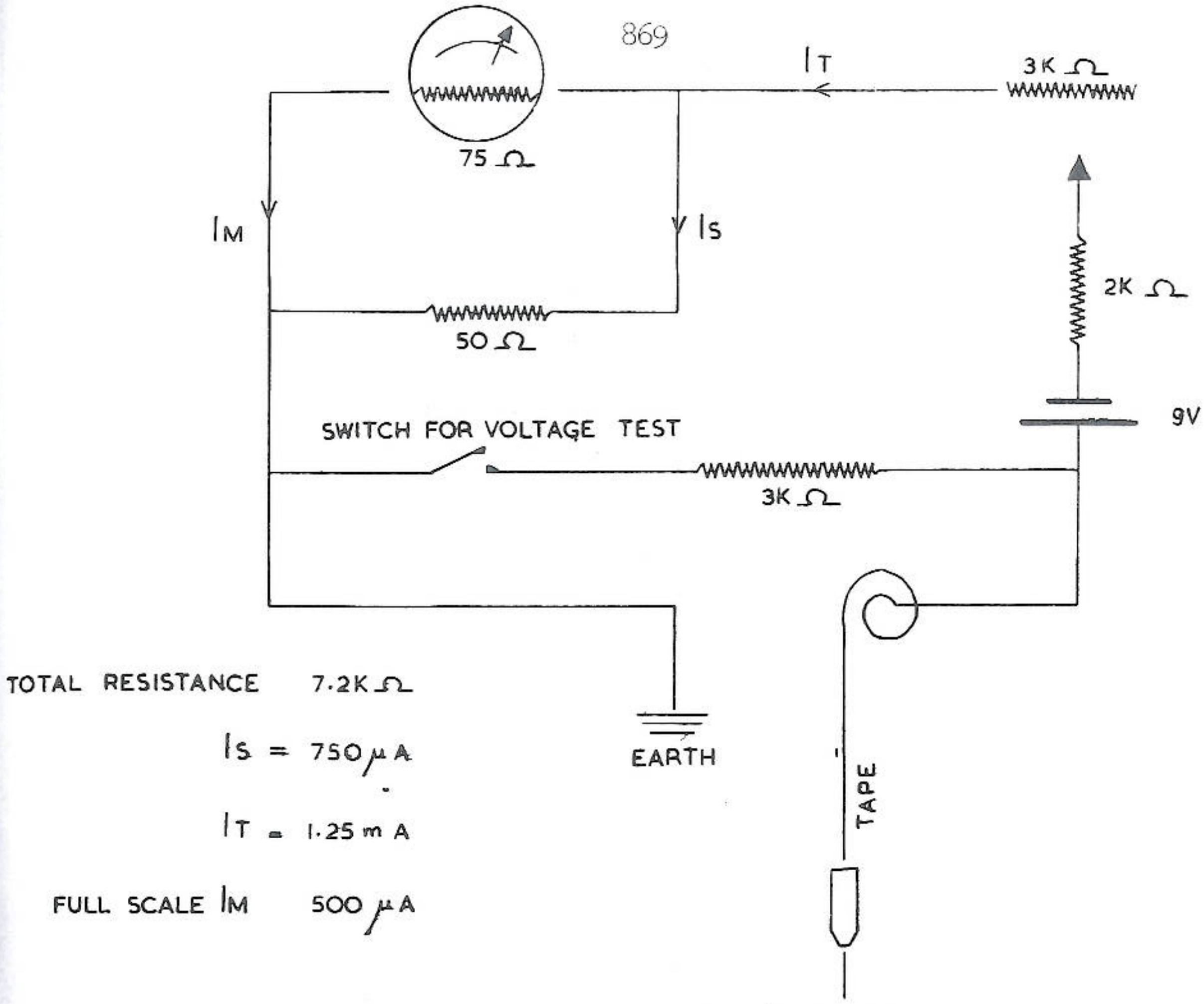

FIG.1 _ ELECTRICAL CIRCUIT OF PROBE

the gauge. This is a difficult requirement to meet if one is referring to the disturbed surface of the open water, although instrumental developments at present in hand may eventually make this possible. Within the well, however, it is a simple matter to devise an electrical probe, which, if attention is given to its operation, will achieve an accuracy better than ± 2 mm.

Such probes have been in use for many years at the Tidal Institute in the day to day maintenance of tide gauges. The basic instrument takes the form of a surveyor's tape mounted in such a way that it can be readily run down the well. Fixed to its extremity is a weighted barrel with an adjustable stainless steel point at its tip. A simple electrical circuit, shown in figure 1, is arranged so that an ammeter records the instant of contact of point and water surface. The ammeter records full scale deflection upon a good contact so that an unsatisfactory contact with floating debris may be recognised and discounted.

For this purpose an adjustment for battery voltage is incorporated. There are of course many acceptable variations of the basic circuit depending upon components available. Again if the point is too fine the signal will be indefinite, showing a slow increase as the point is immersed. The danger here is in systematic under-estimation of water levels. Similarly a point which is too coarse may depress the miniscus at the water surface on entry and raise it upon withdrawal. The ideal seems to be a rod of approximately 2 mm diameter. It is most important that the facility to clamp the tape against a fiducial mark exists, since this greatly increases the accuracy of measurement. Figure 2 illustrates one such instrument built with minimal workshop expertise and in use at Liverpool. Here the detached tube near the point is a gauge used to maintain a fixed probe length.

Practice

The operation of the test now in use in the U.K. involves a small party which occupies a gauge site for a period of 13 hours at the time of a spring tide. At intervals of 15 minutes throughout this period 5 soudings are made in rapid succession. At each instant of contact with the water surface, effected by an experienced tape-man, the gauge under test is read as accurately as possible by a second member of the party. The two groups of 5 readings are averaged, the mean sounding is translated into an elevation above datum by the application of a constant, and the apparent gauge error at this time is noted.

From the data obtained by the exercise a simple diagram can be constructed in which gauge error is plotted against tidal elevation and in which plots from the rising tide are differentiated from those of the falling tide. This is the characteristic response curve of the gauge which is made available for fault diagnosis.

Diagnosis of Faults

The Van de Casteele diagram immediately gives a qualitative illustration of the performance of the gauge and indicates the magnitude of the probable error to be expected in recorded elevations. More important, however, is the facility which the diagram gives to indicate the type of error involved and, possibly, to isolate the fault. The form of the diagram is most instructive to the maintenance engineer.

Figure 3 sets out a number of typical Van de Casteele diagrams upon which brief comment can be made here. It should be noted that the following convention applies to the diagram :

G = Tide gauge reading
S = Well-sounding converted to an elevation above datum
E = Tidal elevation

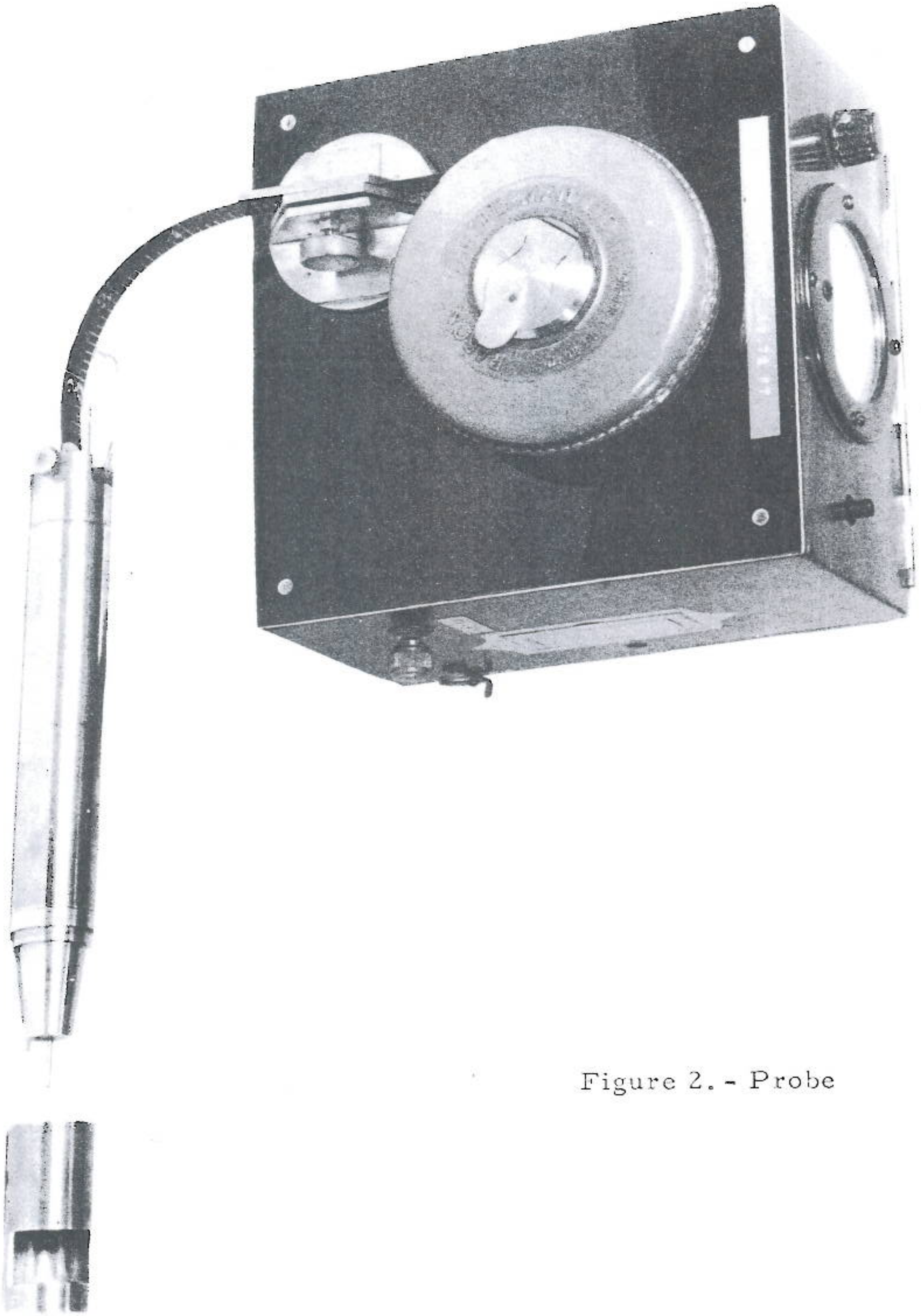

Figure 2. - Probe

→ shows direction of increasing magnitude
R indicates rising tide. Plots shown thus : ●
F indicates falling tide. Plots shown thus : o

I This indicates a perfect gauge. If the soundings have been carried out accurately none of the plots should show a displacement left or right of the line in excess of 2 mm.

II A common test result shows a lag in the response of the gauge to water level movements in the well :
Possible reasons :

(a) Blacklash or friction in the mechanism.
(b) If the gauge is a remote recorder, the lag may be due to the necessity to build up a differential at the well before the remote recorder can respond.
(c) Where sounding is performed off-site, perhaps in another well, this may indicate that the tide gauge well orifice is silted or otherwise too small.
(d) Possibly the float diameter is too small.
(e) Possibly the gauge reading and sounding are not simultaneous. The results are compatible with a procedure in which the gauge is always read before the sounding has been made.

Since almost all gauges show a looped diagram as above, this will now be taken as standard and other faults will be superimposed.

III The fault is systematic non-linearity.
Possible reasons :

(a) The graduations on the tide gauge chart are untrue, either due to poor printing or to the fact that the operating conditions are much more humid than those which obtained at the time of printing. The spacing of the graduations on the chart is too large.
(b) The float pulley diameter is too large. This may be due to the fact that too long a length of wire is attached to the float so that riding turns are always present.
(c) Possible overriding in the pen carriage movement.
(d) Errors in design, gears, pen carriage movement.

IV The fault is systematic non-linearity, of opposite sign to III.
Possible reasons :

(a) The graduations on the tide gauge chart are untrue.
The spacing of the graduations on the chart is too small.
(b) The float pulley diameter is too small.
(c) Possible overriding in the pen carriage movement.
(d) Errors in design, gears, pen carriage movement.

V(i) Here non-linearity is present only in the higher tidal elevations.
Possible reasons :

(a) A classic case of riding turns in the float wire near to high water.
(b) Riding turns in the pen carriage movement.
(c) Since the test is conducted over several hours, during which the drum rotates and different parts of charts are used, the above might indicate that, for approximately a 6 hour's width of the chart, the graduations on the chart have a spacing which is too large.

Condition (c) shows itself more commonly as V(ii) or V(iii).
Also a non-linearity of reverse sign is possible.

VI Here the diagram is vertical at higher tidal elevations but is becoming progressively negative at lower levels.
Possible reasons :

(a) The tension is the float suspension is not constant and this affects the level of buoyancy of the float. The condition is most common where the float suspension is tape rather than wire, and particularly where the counterweight is immersed at high water.
(b) The float suspension is tempered and contains kinks.
(c) The counterweight is of insufficient mass, particularly if the plots for the rising tide are more haphazard than those for the falling tide.
(d) The float diameter is too small, particularly if the plots for the rising tide are more haphazard than those for the falling tide.

VII As in VI but here the diagram becomes progressively positive in the lower levels. Possibly the condition may be due to insufficient mass in the sounding device or kinks in the souding tape. Alternatively a non-constant spring counterpoise to the float may be the explanation.

TYPICAL VAN DE CASTEELE DIAGRAMS

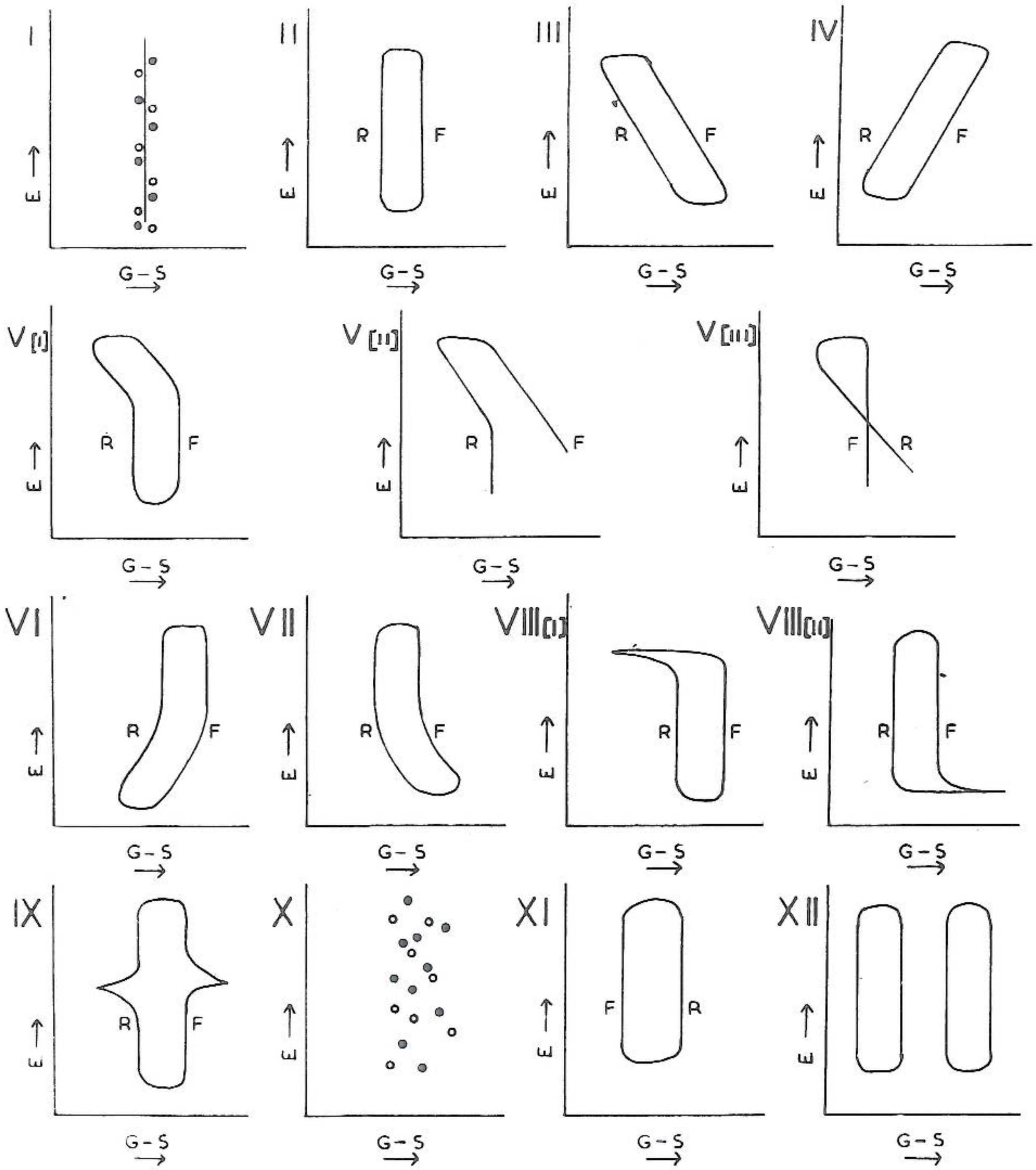

FIGURE 3

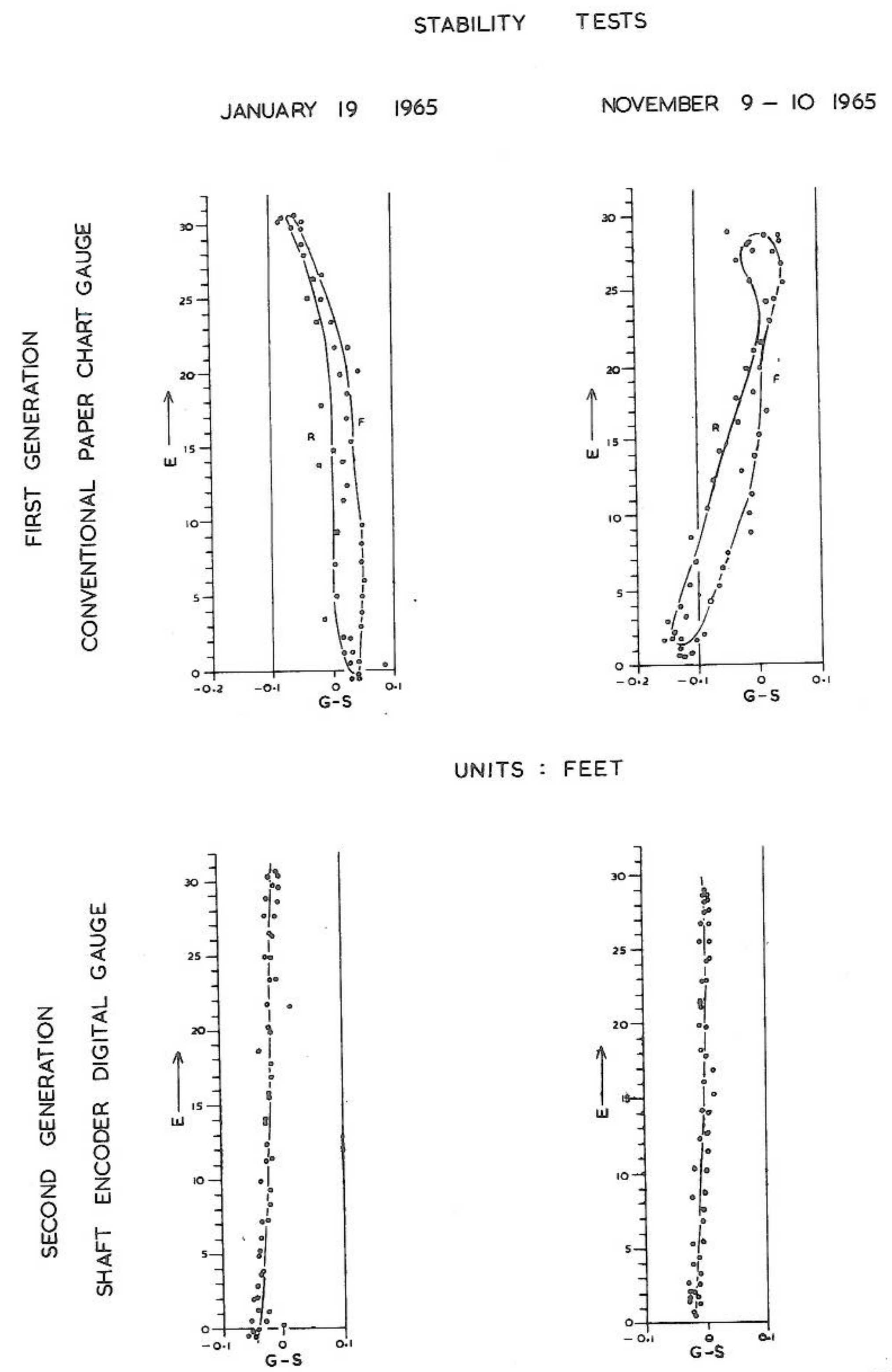
STABILITY TESTS
JANUARY 19 1965
NOVEMBER 9 – 10 1965
FIRST GENERATION
CONVENTIONAL PAPER CHART GAUGE
SECOND GENERATION
SHAFT ENCODER DIGITAL GAUGE
UNITS : FEET
E
G-S
R
F
0
5
10
15
20
25
30
-0.2
-0.1
0
0.1

FIGURE 4

VIII(i) The gauge is unable to register maximum levels due to :

(a) The counterweight falling too low so that it fouls an obstruction.

(b) The float or pen carriage, on rising, reaches an obstruction.

VIII(ii) The gauge is unable to register minimum levels due to :

(a) Siltation of well.

(b) The counterweight rises too high so that it fouls an obstruction.

(c) The float or pen carriage, on falling, reaches an obstruction.

IX Irregularities occur at a fixed level.
Possible reasons :

(a) The float fouls an obstruction in the well on both rising and falling tides.

(b) The counterweight fouls an obstruction on both rising and falling tides.

X Plots from the rising and the falling tide are haphazardly distributed so that no pattern emerges. Most probably this is due to the poor quality of soundings or to unusual difficulties in reading the gauge.

XI The direction of rotation of the diagram is anticlockwise. This condition is difficult to understand in terms of the gauge mechanism, since it implies that the gauge is anticipating movements of water in the well. It is most probably due to faulty sounding equipment or procedure e.g. the sounding and the tide gauge reading are not simultaneous. These results are compatible with a procedure in which the gauge is always read after the sounding has been made.

XII Condition : successive tests give markedly different datums.
Possible reasons :

(a) Poor gauge maintenance in pen setting.

(b) Poor registration of charts on the drum or badly trimmed charts.

(c) Inadequacy of pen mounting.

Note that where a condition may be explained
both (a) by faults in the gauge which occur between the float pulley and the float e.g. riding turns, float buoyancy, counterweight etc.,

and (b) by faults in the gauge which occur between the float pulley shaft and the chart e.g. gearing, friction, pen carriage, chart graduations, it can easily be decided whether faults of (a) or (b) type apply by :-

1. disconnecting the float suspension from the float,

2. determining the designed diameter of float pulley (often an integral number of units),

3. scribing a mark on the float pulley which can be made to register against a fixed pointer,

4. rotating the float pulley slowly and precisely through one rotation at a time from minimum level to maximum level and back to minimum level noting the pen reading at each rotation. The procedure should then be repeated from maximum level through minimum and back to maximum.

Errors of type (b) are shown by inconsistencies in the successive displacements of the pen, otherwise the gauge faults must be classed as of type (a).

Stability

The value of the Van de Casteele test is considerably enhanced if a regular programme of tests is conducted. In the case of many of the first generation of tide gauges the susceptibility to faults is so marked that the performance of the gauge is continually changing. It is important to be aware of this condition if it exists. Figure 4 illustrates this point and stresses the advantage which second generation digital gauges have when relieved of the danger of those faults inherent in the paper chart, drum and pen carriage.

Comparative Tests

The suggestion immediately arises that the test can be used as a basis of comparison between the efficiency of one gauge, or group of gauges, and another. The Tidal Institute has an unusually large stilling-well at Birkenhead, approximately one metre in diameter, over which it is possible to mount a number of tide gauges. In recent months this has been used for the specific purpose of comparative tests. In these, the instruments are clearly attempting to measure the same phenomenon and, if a sufficiently large survey party is available, it is possible to use the same well soundings to test the performance of a number of instruments. The results of one such exercise which involved four instruments is given in Figure 5. The instruments in question covered, as far as possible, the full range of tide gauge types at present available :-

COMPARATIVE TESTS JANUARY 30 1968

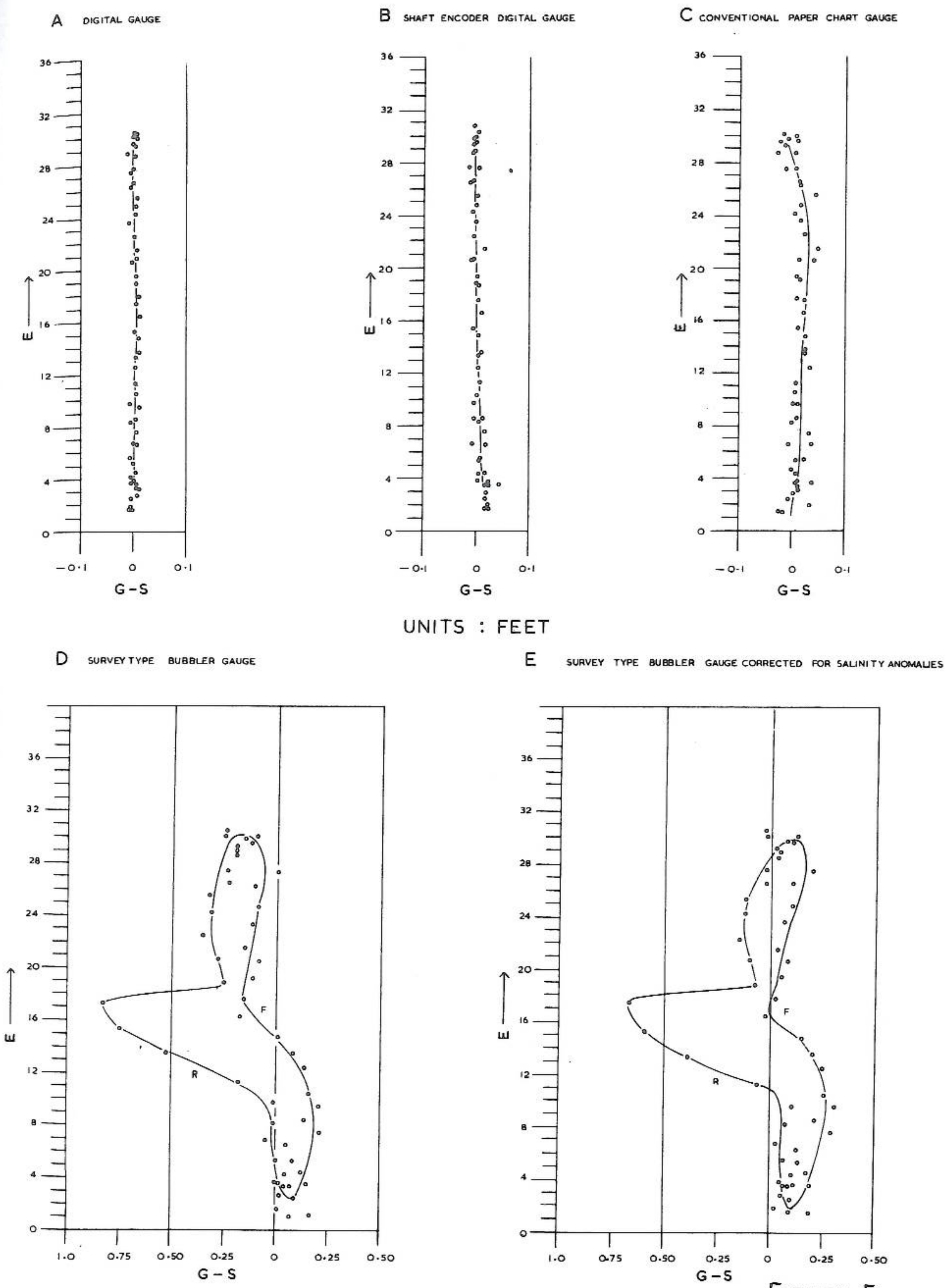

FIGURE 5

A. a digital gauge which uses a large diameter float to overcome problems introduced by extensive gear trains and also by a simple counterpoise system which allows the counterweight to descend into the well as the float rises.

B. a shaft-encoder digital gauge which uses a small diameter float with a counterpoise provided by a tensator spring. It is probable that the latter does not provide a truly constant tension in the float tape.

C. a conventional paper chart gauge which has a performance rather better than average for its type. In particular there is little evidence of friction or backlash but the scatter of plots shows the inability to read the paper chart with precision.

D. a less precise survey instrument which claims only an accuracy of ± 1% and which depends upon the principle of escaping gas through the open end of a long submerged tube as a pressure sensor.

Instrument D is calibrated on the assumption that sea water density has a constant value of 1.025. The tests in this case were accompanied by the measurement of salinity and temperature profiles within the well. On the basis of depth mean densities so determined it was possible to adjust the results and their corrected form appears in the diagram marked E. In D and E there is a large lobe extending to the left near to midtide. The explanation of this feature seems to be associated with a temporary partial blockage in the pressure sensor which was relieved by increasing the flow of gas for a time.

General Tests on Design and Engineering

When a testing programme is enlarged in scope so as to include regular exercises at a large number of gauge installations, yet another service is technically possible. It is often difficult for a tide gauge manufacturer to retain an intimate knowledge of the performance of his products and their ability to meet the changing requirements of the user. Again in many cases he has produced an instrument in an attempt to match a set of specifications rather imperfectly prescribed by the oceanographer. From the user's point of view, the decision as to choice of instrument for a particular environment and application is difficult without detailed evidence of performance. Modern manufacturing techniques may be excused for producing an occasional sub-standard instrument but rigorous tests applied uniformly to a large number of operational installations can provide useful information. For example, if the observational data obtained as the basis of the Van de Casteele test is examined statistically, it is a routine matter to determine, say, the standard deviation from the mean of a single elevation. When considering a group of gauge installations it is advisable to apply a weighting system based upon tidal range if producing statistical evidence of the performance of the group. An illustration of one of many possibilities is given in the following table :

Mean Standard Deviation weighted according to spring range

Age Group	Manufacturer A	Manufacturer B
0 - 5 years	0.914	Nil
5 - 10 years	1.947	1.158
10 - 15 years	Nil	1.280

UNIT : CMS

This simple analysis suggests that either Manufacturer A has recently improved the quality of his product or alternatively that his instrument shows a significant loss of performance with age. The products of Manufacturer B are possibly more consistent and certainly, in the period 5 to 10 years prior to the test, this manufacturer appears to have produced a more satisfactory article.

U.K. Practice

In recent years in the U.K. advances have been made in the prescription of specifications for the performance and maintenance of tide gauges. This progress originally arose out of storm surge research interests which are sponsored by the Advisory Committee for Oceanographic and Meteorological Research and administered by the Ministry of Agriculture, Fisheries and Food. The shortcomings of the basic data were continually apparent in this work so that the need for the establishment of a Working Party on Tide Gauges was realised. This Working Party is now concerned with a national network of some 38 tide gauges installed at strategic locations around our coasts monitoring tidal levels for a variety of associated purposes:- storm-tide warning, storm surge research, tidal analysis, mean sea level studies, numerical and electronic analogue models of seas and estuaries. The administration of this network leans heavily upon performance diagrams of the Van de Casteele type produced regularly in a routine program. Each mainland installation is visited at six-monthly intervals by a regional survey party from the Ordnance Survey which inspects and reports upon the equipment and its maintenance. The relationship in level between visual tide staffs or local contact marks and the appropriate tide gauge bench mark is checked and, at least on one occasion annually, a full Van de Casteele test is performed. The test is also utilised in acceptance tests when a manufacturer provides a new gauge.

Acknowledgement

It is necessary to acknowledge the work of several members of the staff of the Tidal Institute who have assisted in the exercises described above.

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