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PERFORMANCE TESTS OF A) AN OTT DIGITAL TIDE GAUGE AND B) A NEGRETTI AND ZAMBRA BUBBLER TIDE GAUGE

BY

G W LENNON AND D L LEIGHTON

1968

institute of coastal oceanography and tides
NATURAL ENVIRONMENT RESEARCH COUNCIL

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This Report was produced before the
Tidal Institute became the Institute
of Coastal Oceanography and Tides

Description

The Ott Punched Tape Water Level Recorder is designed to fulfil the normal requirements of a conventional tide gauge. It should be mounted over a stilling-well, whereupon the movements of its counterbalanced float are registered in a four digit display through a mechanical counter (see Fig. 1(3). At a specified sampling interval, commonly 15 minutes, a Kienzle batter-wound clock (see Fig. 2 (4)) initiates a recording cycle whereby coding discs, incorporated in the mechanism, arrange that the four digits, shown at this instant in the counter, are punched serially, together with a spacing character, on to computer-compatible 5-hole tape. The tape arrangement is shown in Fig. 1. Two punching codes are offered, the CCITT International Teletype Code and the Ferranti Code although other five-channel codes are technically possible. The power supply is provided by a 7·5 volt dry battery which, together with the record tape supply, has sufficient capacity for a recording period in excess of six months. The battery condition can be checked rapidly and simply by the volt meter provided (see Fig. 1 (8)). The number of punching cycles in a record is shown by a second counter (see Fig. 2 (5)) and this can be reset to zero at will using a knurled knob (see Fig. 2 (6)). A small sprocketed pulley (see Fig. 2(1)) drives the level indicator and coding discs through gear trains, the pulley in turn being driven by a perforated stainless steel tape which passes from the float round the pulley and down to a counterweight (see Fig. 3). The hanging position of the perforated tape can be adjusted by means of two moveable arms fitted with idler pulleys shown in the lower part of Fig. 2 and also in Fig. 3. The instrument is well-engineered of high quality materials and is enclosed, complete with battery, in a solid metal case which is weatherproofed and secured by locks.

The instrument provided for test was supplied with a large float of 500 mm. diameter to cover a range 0 to 9·999 metres with an accuracy of measurement stated by the manufacturer to be 0·5 mm. and with a reading accuracy of 1 mm.

Initial Comments

A booklet containing specifications and operating instructions was provided with the instrument. In spite of its brevity, this has proved to be remarkably clear and adequate with two exceptions:-

1) Fig. 3, extracted from the booklet, proved to be in error, if the instrument is to be used for the metric scale. The positions of float and counterweight should be reversed in this case.

2) No mention is made of the elaborate measurements and calculations which are required in order to determine the maximum and minimum permissible length of the perforated tape so as to avoid the risk of the counterweight fouling the well-base on the one hand or the fitments at the well-head on the other. See Fig. 4 which illustrates this point.

A further minor point of criticism is that although the Kienzle clock readily shows time of day by conventional hour and minute hands, it is not possible to anticipate easily at what instant the clock will trigger the punching cycle. The rotating minute disc is fitted with four pegs which in turn come into contact with a wire fixed to a microswitch. Contact between peg and wire is maintained for almost ten minutes in each quarter hour and it is at some time during this period that the switch makes without any prior physical indication.

Previous experience with a float/counterweight arrangement of this type causes concern in that it is necessary for the counterweight and a considerable length of the perforated tape to become immersed in the water of the well. The wetted tape then passes over the sprocketed float pulley with a consequent danger that a silt build-up or possibly corrosion might occur. The makers gave the assurance that the material of the pulley, (aluminium alloy AL-Mg5 eloxadised) would resist corrosion although the danger of disengagement of sprockets and perforations through silt accumulation presumably remains.

Programme of Tests and Comments

The instrument was made available late in September for a period of six months initially. Unfortunately a series of faults have been discovered throughout the period of five months which have elapsed up to the time or writing this report so delaying full operational tests of the equipment. The difficulties are outlined below:

1) In making preparations for installation it was noted that it was impossible to achieve sufficient spacing between the float suspension and the counterweight suspension, within the confines of the instrument case, so as to avoid fouling of the float by the counterweight. The manfacturer's agents first recommended the cutting of holes in the instrument case but this solution was found to be unrealistic. The final solution was to substitute a 200 mm float for the original 500 mm version. This caused an inevitable delay and introduced anxiety over accuracy. The accuracy of measurement of a 200 mm float has not been quoted by the manufacturers but it is significant that their specifications suggest a reduction in accuracy of measurement from 1 mm to 2-3 mm when a change is made from a 500 mm float to a 300 mm float.

2) The 200 mm float was supplied without a matched counterweight and the instrument was installed using the counterweight originally provided for the 500 mm float. This was clearly too heavy as the float consequently rode too high in the water. Since it has a conical base this condition had the same effect as would be achieved if a small diameter float was in use and the driving force applied to the mechanism was therefore too small. The agents were able to quote the recommended mass, 600 grams, for a counterweight for use with a 200 mm float and a replacement was hurriedly made at this Institute.

3) In spite of the above adjustment, the mechanism proved to be insensitive to small water movements. There was clear evidence of friction in the mechanism so that the elevation indicator moved discontinuously through steps of the order of several centimetres. The junior digit, representing millimetres, had no signicance whatsoever. In addition, at certain combinations of displayed digits, the coding discs were found to lock completely. Attention by the company's maintenance engineer was prompt and effective. The major fault was found to be in the coding discs. These are manufactured from extremely hard metal, which creates engineering problems. The discs in question were found to possess burrs on their edges which prevented free independent movement and explained the tendency to lock. The replacement of the coding discs with further friction in the gear trains, in particular the drive to the elevation counter which is achieved through small bevel gears. A considerable time was spent in adjustment so as to ensure an optimum gear mesh; later the elevation counter and its bevel gear were replaced.

4) It was pointed out by the engineer that by transferring the sprocketed float pulley from one shaft to another available on the instrument, it was possible to change the recording system from metric measurement to foot measurement. This change converts the instrumental reading range to 0-99·99 ft. with a reading definition of 0·01 ft. The immediate advantage of converting to the foot system is that

certain gears are eliminated so that friction and backlash are thereby reduced. This was effected.

5) At this time it was noted that the perforations of the float tape did not break cleanly from the sprockets of the float pulley. The engineer was able to inform us that a modified design of sprockets and perforations was available. Consequently a replacement float pulley and float tape were provided.

6) The paper tape supplied with the gauge was stated to have a 6% oil content so as to resist effects of humidity. Nevertheless, a change of policy of Messrs. Ott in this respect was reported to apply to later models. This involved the supply of plastic tape which is less liable to the effects of humidity and to physical damage. A plastic tape was subsequently provided for these tests.

The above adjustments were complete and the gauge ready for operational tests by January 17th, 1968.

Test Programme

A gauge of this type should be tested in three respects:-

(a) Its accuracy of measurement which may be interpreted as the ability of the mechanism to record with precision, on its elevation counter, the movements of the water surface contained within a stilling well. Such tests can be made using the Van de Casteele test in normal use at the Institute whereby the elevation displayed is checked against soundings made with an electrical probe at frequent intervals throughout a tidal cycle at springs.

(b) Its reading accuracy which may be interpreted as the ability of the mechanism to transfer the elevations, shown by the digital counter, at predetermined intervals on to the punched tape in such a manner as to allow an electronic computer to interpret the record satisfactorily. It is proposed to investigate this matter by computer techniques supplemented by separate checks on clock performance.

(c) Its ability to retain a high quality performance and hold a fixed datum over long periods. In view of our limited experience of the gauge at this time a minimal contribution can be made under this heading.

Accuracy of Measurement

On January 30th, the opportunity was taken to use spring tidal conditions for the application of an elaborate Van de Casteele test. A team of assistants prepared to test against one set of electrical probe soundings a number of tide gauges installed over a single large diameter stilling well at Alfred Dock, Birkenhead. In addition to the Ott gauge a Fischer and Porter digital gauge and a conventional Légé analogue gauge some twelve years old were numbered among the gauges included together with special attention to procedure ensured that the performance of the several gauges could be directly compared.

The tests were undertaken with some anxiety as to the ability of the Ott gauge to respond to small changes of level in the water surface. A history of mechanical short-comings had been experienced and it was notable that by comparision with the Fischer and Porter gauge, for example, the existence of an extensive gear train with associated friction and backlash was not in its favour. Again the float counterweight arrangement was clearly inconstant in that over a 30 ft tidal range the tension in the float tape will vary according to the height of tide through a range equivalent to the weight of 2 x 30 ft. of perforated float tape. The buoyancy level of the float might therefore be affected. Before amendments were made to the Fischer and Porter gauge by the fitting of a tensator counterbalance system the latter effect had been shown to be significant in that case.

The VdC diagrams produced by the measurements of January 30th are shown in Figures 5, 6 and 7.

The diagram for the Ott gauge shows a remarkably vertical pattern which indicates a zero calibration error. This implies a high quality of design and engineering and an accurately perforated float tape. Bearing in mind that the accuracy of sounding has been shown elsewhere to be of the order of ± 0·0005 ft., the magnitude of the plotted error suggests that the accuracy of measurement of the Ott gauge is of the order of ± 0·01 ft.

This diagram is unique and indicates a performance superior to any yet met in the course of an extensive program of VdC tests in this country. By comparison the Fischer and Porter gauge shows a small non-linearity at low tidal elevations giving errors of the order of + 0·02 ft. to + 0·03 ft. near to tide gauge zero. This condition is identical to that found on the occasion of the last VdC test of this gauge conducted in June 1966. This is a consistent fault of the Fischer and Porter gauge but it should be noted that its magnitude is small and unlikely to be significant in most applications.

The diagram for the Légé shows a performance rather better than average for a conventional analogue gauge. Nevertheless the non-linearity of the calibration associated with small design faults, possibly riding turns in float and pen carriage drives and the use of paper charts is noticeably much greater than that shown by the digital gauges.

Accuracy of Reading

A simple computer program has been written to enable the first paper-tape record to be passed through the KDF9 computer of the University of Liverpool. The program lists the contents of the tape and plots the elevations so as to stimulate the conventional analogue tidal record. The latter gives the opportunity to quickly scan the record so as to provide an estimate of smoothness.

This test gave a generally satisfactory result although at one point of the tape the computer read a recorded item as a single digit rather than a four digit number. The result was that one elevation was read as 0·01 ft. instead of its correct value of the order of 14 ft. A second pass through the computer met with failure near to the same part of the tape. The error this time was different and in fact the computer failed to read a spacing character so that two adjacent records were merged to give a tidal elevation in excess of 140,000 ft. All subsequent readings would be associated with a 15 minute error in consequence. An examination of the punched record showed that this was undamaged, cleanly punched and correctly represented the digital form of tidal elevation in Ferranti code. However, it was perceived that throughout the tape, the sprocket holes used to drive the tape through both gauge and computer were out of alignment with the punched digital characters. It was suspected that since the computer uses the sprocket holes for reading registration, that this was the cause of the difficulty. In this connection it is significant that the sprocket holes are not punched by the gauge but that the tape is supplied with these holes pre-punched. Reference to the agents on this failure produced the information that Messrs. Ott have again introduced a modification, dated January '68, whereby models supplied subsequent to this date will be fitted with an amended punching mechanism which will punch the sprocket holes and that in future the record tape will no longer be pre-punched.

In the discussion of punching difficulties which ensued, we were informed that reading failures had been associated elsewhere with irregularities in the oil impregnation of the paper tape. When approached with the record from the Birkenhead gauge, the Computer Engineer of the University Computer Laboratory was of the opinion that the off-punch condition was not serious enough to cause failure and that the fault could be associated with the irregular translucent condition of the tape produced by the oil application. Further tests using plastic tape rather than paper tape will be of interest in this respect.

On all occasions when attention has been given to the gauge, it has been verified that the sample counter has been consistent with the elapsed time indicating that the punching mechanism has operated on the correct number of occasions and consequently that the recorded items are correctly spaced in time. Some little concern has been occasioned by the Kienzle clock which to date has shown a performance barely tolerable. Constant regulation has been required and it is hoped that the clock will settle down, accommodating itself to the conditions of the tide gauge hut and in fact there is some evidence to show that this is taking place. Meanwhile errors up to 5 minutes in magnitude over one week have been noted.

Long Term Stability

In view of the limited duration of these tests it is not possible to express a rounded opinion of the long term reliability of the gauge. It can be said, however, that in accordance with our experience of other digital, rather than analogue, gauges the performance of the Ott instrument displays an ability to retain a fixed datum within fine limits.

The greatest cause for concern under this heading is directed towards the float counterweight arrangement and the danger of the build-up of silt on the float pulley. In time this accretion could well affect the fit of the float tape perforations on the sprockets and eventually the danger may arise whereby the float tape will become disengaged from the sprockets. Experience with the Fischer and Porter gauge, when this had a similar arrangement, showed that serious failure caused by such disengagement occurred after an interval of only two months.

A final comment upon the recording tape is appropriate. The manufacturer's representative was asked for his opinion on the long term durability of the punches particularly when the thicker plastic tape is in use. The answer given was that the plastic medium, being free from fibres, caused less wear in the punches than paper tape. A contrary view is expressed by the Computer Engineer based upon experience with computer ancilliary equipment. In fact concern was expressed at the ability of the punches to survive a long recording period if plastic tape is used. This problem remains unresolved.

Attempts are now being made to arrange for the instrument to remain under test at Birkenhead for a further six months so that long term effects may be evaluated.

General Comments

It is our opinion that the Ott gauge has an attractive potential in spite of the succession of teething troubles which have been experienced during these tests. At all times the manufacturers and their representatives have been most attentive and the services of an engineer have been provided at short notice upon the three occasions when attention or advice has proved necessary. In this connection it must be acknowledged that we may have had the advantage of a priviliged position since it is known that the particular instrument is under test and that consequently it is in the interests of the agents to provide priority attention. Some concern is felt as to whether a normal tide gauge user would readily recognise the shortcomings which necessitated attention in our case and it may be that, unkown to the user, a long period of useless record would be accumulated before faults were recognised. It should be noted, however, that many of the faults which came to light in the Birkenhead tests were known to the manufacturers who had already taken steps to avoid recurrence in future models. The modifications effected indicate an uncommon readiness to produce a high class instrument to users requirements. It is felt that the manufacturers would agree that over the recent few months the instrument has been under development so as to evaluate and to rectify teething troubles.

The general workmanship and design is excellent although the wisdom of providing fine bevel gears in the elevation counter drive is questionable. The VdC tests show a commendable accuracy of measurement hitherto unmatched elsewhere. In spite of extensive gear trains, which are essential in any mechanism required to punch computer-compatible tape, this achievement is made possible by the conviction of the manufacturers that accuracy is intimately associated with float size. The fact that larger diameter floats provide a greater driving force to overcome friction is apparently not fully appreciated by many manufacturers. Again the VdC tests indicate a virtual absence of backlash which is surprising in the circumstances.

The provision of computer compatible tape is a distinct advantage which provides ready, rapid and accurate access to the data when required. This facility outweighs the two inherent minor disadvantages which are as follows:-

(a) The Ferranti or Teletype code is less easily read by the tide gauge operator than, say, the 16 channel Fischer and Porter tape which is preprinted with regard to coding and time. It should be noted here that the Ott gauge may be fitted with ancilliary equipment to provide a printout of recorded elevations on site.

(b) The punched tape output will normally be the single source of the recorded information to be kept on file and also to be passed through a computer when required. The risk of damage or loss is thereby to be faced. The tape could of course be copied at an early stage although tape duplicating processes are notably unreliable and such a procedure would need to be accompanied by a computer verification program which would compare the original with the copy. Again note that the use of plastic rather than paper tape at least reduces the risk of damage.

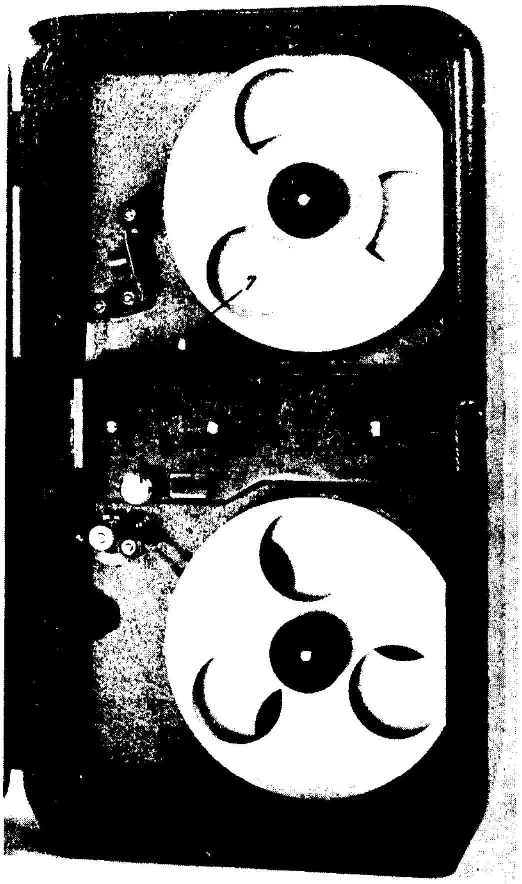
Experience with digitally recorded time series is always associated with concern over timing and sampling reliability where time is not sampled and recorded along with the investigated phenomenon by an independent clock. If for example an Ott user should ever find that the sampling counter reading is less than that required by the elapsed time then it may be that the entire record may be worthless. In the interests of unnecessary sophistication and escalating costs it may be unreasonable to suggest that time sampling should be considered by the manufacturers of such a gauge but in the absence of time sampling every attempt should be made to provide a high quality clock and a reliable sampling mechanism.

It should be noted that Messrs Ott do provide a facility whereby the record can be transmitted over great distances. This would seem to fill a growing need for the monitoring of tidal levels at distant sites such as, for example, in the monitoring of storm surge conditions.

An appropriate final comment would be that all indications suggest that for research purposes, and elsewhere when immediate access to an analogue record is unnecessary, the Ott gauge will record movements in a stilling well with great precision and probably more accurately than the ability of the stilling well to represent the conditions in open water.

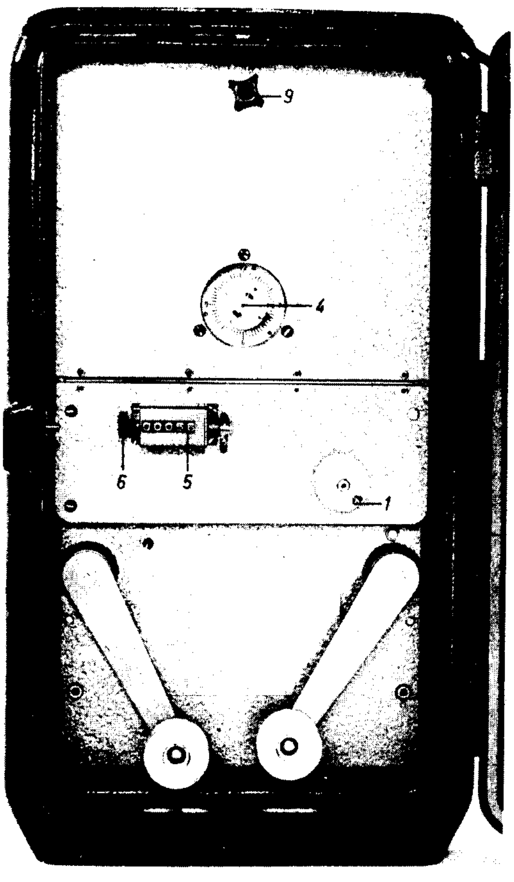
The assistance of Mr. R. Rowles in writing the computer program to which reference is made and of Miss Claire McDonald, Mr. G. A. Williams, Mr. R. White, Mr. S. Gates and Mr. M. Blair in the VdC test procedures is hereby acknowledged.

FIG 1



218.31

FIG 2



218.32

FIG. 3

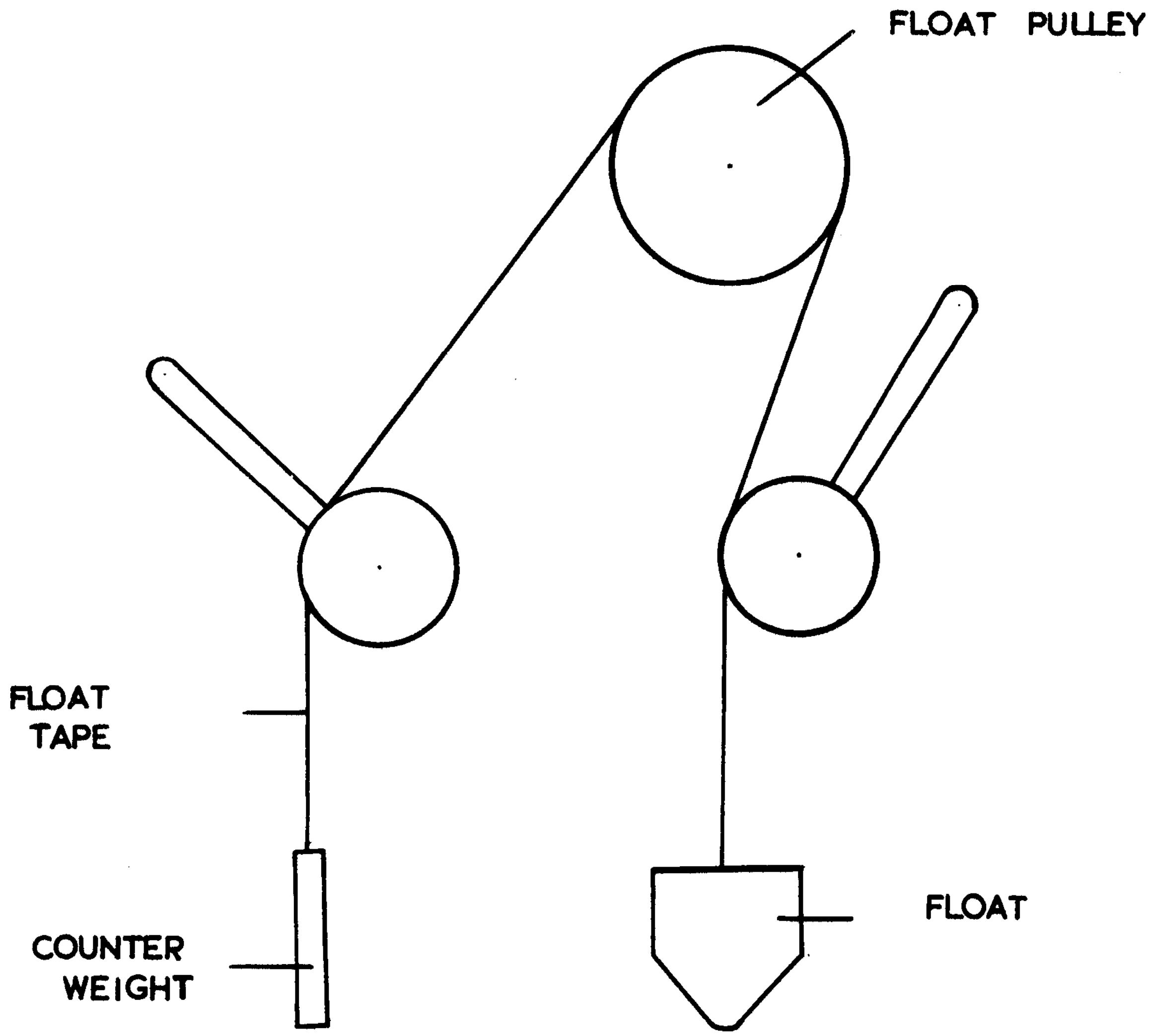
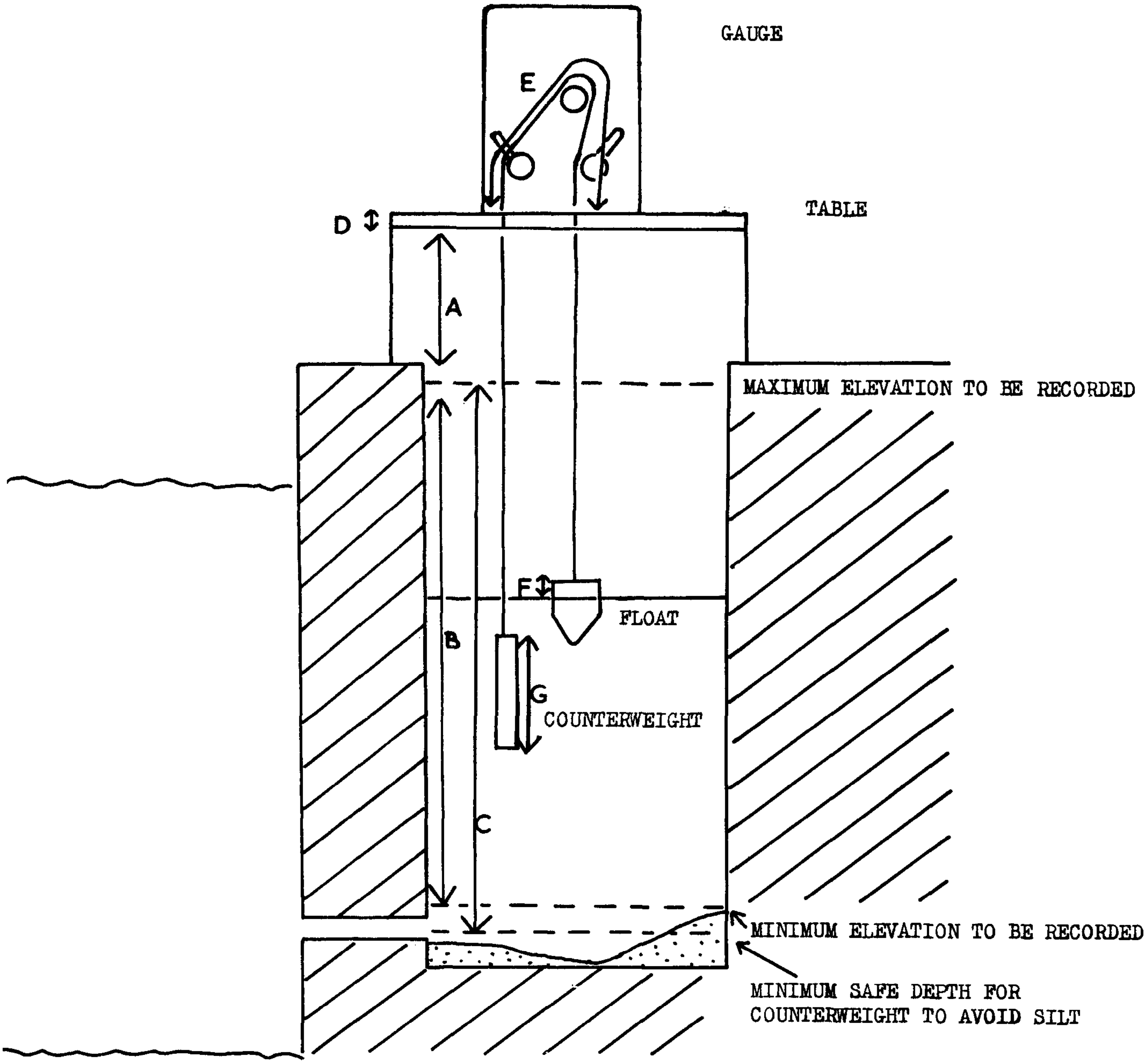


FIG 4



MINIMUM LENGTH OF FLOAT TAPE depends on condition at low water. Counterweight must not foul fitments at well head (perhaps in this case underside of table).

MINIMUM LENGTH = A + B + E + 2D - F
(At Birkenhead this minimum is 14·75 metres)

MAXIMUM LENGTH OF FLOAT TAPE depends on conditions at high water. Counterweight must not foul any obstruction at a low level in well (perhaps in this case the silt at base of well).

MAXIMUM LENGTH = 2A - F + E + 2D + C - G
(At Birkenhead this maximum is 16·64 metres)

A 20 metre tape length was provided which if not shortened fails to meet requirement of maximum length.

Tests of a Negretti and Zambra bubbler-type tide gauge

The Negretti and Zambra tide gauge is designed primarily for survey use where tidal measurements are required on a shelving shoreline or at other sites where, through urgency or financial or physical considerations, the installation of the conventional stilling well is not possible.

The gauge consists of the following components:-

(a) A high pressure cylinder containing compressed air or gas at a pressure of 2000 PSI.

(b) A high pressure regulator which reduces the primary pressure of 2000 PSI to a value of the order of 15 PSI.

(c) A differential pressure regulator which reduces the secondary pressure of 15 PSI to a value of 1·5 PSI and by a feed back system ensures that an output pressure of 1·5 PSI remains constant over and above any back pressure applied to the system.

(d) A needle valve which allows gas to escape from the differential pressure regulator at a controlled rate.

(e) A glass sight gauge which shows the rate of escaping gas in the form of bubbles rising through a glass water container. The needle valve can be adjusted so that a slow rate of escape is achieved (one bubble per second).

(f) From the sight gauge the escaping gas passes along a 1/4" (outside diameter) nylon tube, which can be of great length, and its open end is to be secured at a fixed elevation under water. Provided that the gas is escaping at the open end of the submerged tube, the back pressure experienced in the tube is a function of the head of water above the open end of the tube.

(g) In order to monitor this back pressure, a tapping is made to the system on the output side of the sight gauge. This tapping is connected to the aneroid capsule stack of a conventional barograph in which a pen record is made on a chart affixed to a rotating drum.

Two models are available for standard ranges 0 to 15 ft. and 0 to 30 ft. respectively and calibration assumes a fixed specific gravity of sea-water of 1·025. The charts have a small vertical scale (6 tidal feet = 1 recorded inch in the 0 to 30 ft. range) and the time ordinates are inconveniently curved so as to accommodate a radially moving pen. The manufacturers claim something better than 1% accuracy. A 65 cu.ft. capacity Aqualung cylinder is reported to be adequate for one month's record, provided all connections are sound and the gas escape is regulated to a low level. The barograph however has an 8 day clock and the chart is recommended to be changed at least once per week. The chart is fixed to the drum by double-sided adhesive tape.

Before putting the instrument into operation it is advisable to insert a blank into the output gland of the instrument and to test that both primary and secondary pressure dials remain steady over a period of several hours.

Performance Test

On January 30th 1968 a 0 to 30 ft. range version of the gauge was installed in the Alfred Dock stilling well and its performance tested on the basis of the VdC tests which also allowed comparison with an Ott digital gauge, a Fischer and Porter digital gauge and a Légé analogue gauge, 13 years of age. For this purpose a 300 ft. length of 1/4" OD Nylon tube was used as the sensor and the open end of this tube was fixed at the level of Chart Datum in the well.

Since the same well soundings were used for the tests on the four gauges named above, the VdC performance diagrams allow a direct comparison to be made of the respective efficiencies of the different gauges.

Figure 8 shows the results of the VdC test which fortunately was able to cover almost the full range capability of the gauge viz. 30 ft. The following comments can be made:-

(a) The fact that plots from the rising tide are generally to the left of plots from the falling tide, indicates a lag in the instrument's ability to respond to a change in the head of water. In fact examination of the recorded trace shows a miniature step-form which is consistent with this finding. The lag seems to be in the mechanical linkages between the aneroid capsule and pen arm or in the capsule itself rather than in friction between pen and paper.

(b) The error diagram is inclined in a negative sense with increasing tidal elevation indicating a calibration fault. Such a fault was anticipated since in an estuary location, water densities are obviously less than the design value of 1·025. In order to evaluate the error due to density anomalies, salinity and temperature profiles of the water contained in the well were taken on four occasions during the test: at high water, at low water and at mid-tide on both rising and falling tides. The depth-mean density of the well water above the open ended purge tube was found to vary between 1·013 at low water and 1·017 at high water. The associated error in level, due to the discrepancy between the above values and the standard, 1·025, was calculated and is plotted as a continuous line in Figure 8.

(c) A second VdC diagram was constructed (see Figure 9) in which the error due to salinity discrepancy was removed from the data. The effect is to modify the inclination of the diagram, as shown in Figure 8 and in general to verify the calibration of the instrument.

(d) The pronounced negative lobe at mid rising tide shown by the VdC diagram is a distinctive feature and requires explanation. The fault was noted during the VdC test procedure and was corrected by temporarily increasing the rate of escape of gas. The artificial heating in the tide gauge hut was noted to be somewhat oppressive at this time so that it was suspected that the mechanical transducer (aneroid capsule and pen linkage) might be temperature sensitive. Consequently on February 27th further tests were conducted, this time on a falling tide. Over a period of two hours, probe soundings were used to check the readings of the bubbler gauge, which, during this period has raised in temperature from 2·3° C to 39·5° C and then allowed to fall slowly to ambient temperature. The maximum gauge error did not exceed 0·26 ft. and there was no clear correlation between the magnitude of the error and temperature. This being so an alternative explanation of the lobe was sought, it being noted that this must be associated in some way with conditions apertaining to a rising tide.

(e) In order to investigate more intensively the nature of the fault the record of the bubbler gauge was compared over several days with that of the Légé gauge. The latter instrument has a performance which is well known and its probable error is of the order of ± 0-05 ft. (See report on Ott gauge Figure 7.) Consequently the discrepancy between the Légé gauge and the Negretti and Zambra gauge, considered instantaneously, can be regarded as an error of the latter instrument. The pattern of errors produced by this test showed a distinctive and repetive form. In all cases the falling tide was well represented by the bubbler gauge. So also was the rising tide at neaps but not so at springs. On the rising tide at springs a significant lag in the response of the bubbler gauge appeared quite early and this gradually increased until approximately two to three hours before high water. Thereafter the error decreased, and by one hour after high water was negligible. The pattern of the error was somewhat irregular but in general the greater the range of tide, the greater was the anomaly. On a 29 ft. range this error reached a magnitude of 6 ft. Figure 10 illustrates the feature. It would appear from this comparison that the instrument is unable to respond quickly enough to the very rapid rise of levels at spring tides, which in the diagram can be seen to lie between 8 and 9 ft. per hour. It has previously been noted that the record trace of the bubbler gauge shows a stepped pattern and further inspection showed that this condition was more marked on the rising tide than the falling tide. The suggestion therefore arises that some mechanical malfunction is present and that further, the capsule stack possesses an asymmetrical response so that its performance in the presence of increasing pressure is inferior to that in the presence of falling pressure. Possibly, but less likely, the mechanical linkage between capsule and pen arm may be suspect in this context. Whatever the cause, this fault represents a serious criticism of the instrument. In particular the record itself is quite smooth and the presence of the error would remain undetected in all applications except where comparison can be made with another instrument.

Finally, after some days of operation the records began to show a further defect in that spring low waters were seen to be incorrectly represented. In fact the pen was apparently unable to record a level below 1·6 ft. above datum, although the full range of the chart had initially been covered without difficulty. Some days later the anomaly was found to occur at level of 2.0 ft. above datum. A resetting of datum in terms of the elevation of the open end of the purge tube was not found to be necessary so that a second unresolved difficulty now exists.

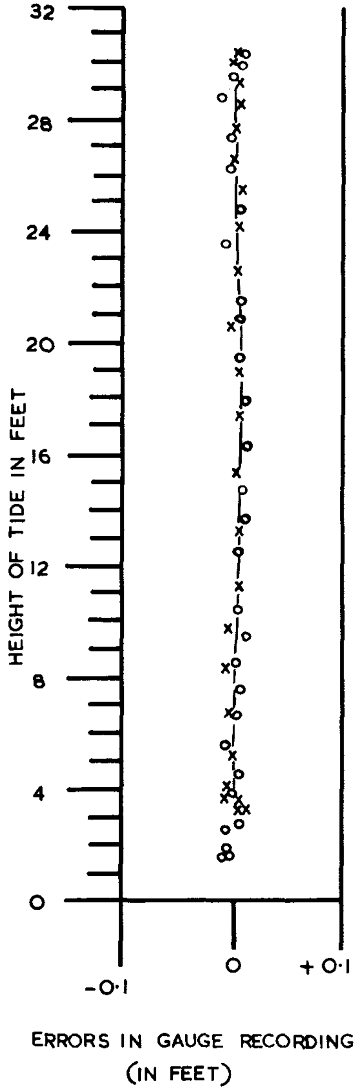
These criticisms will be put to the manufacturers for comment and advice.

JANUARY 30 1968

PLOTTED QUANTITIES ARE TIDE GAUGE RECORDING MINUS WATER HEIGHT DETERMINED BY WELL SOUNDING

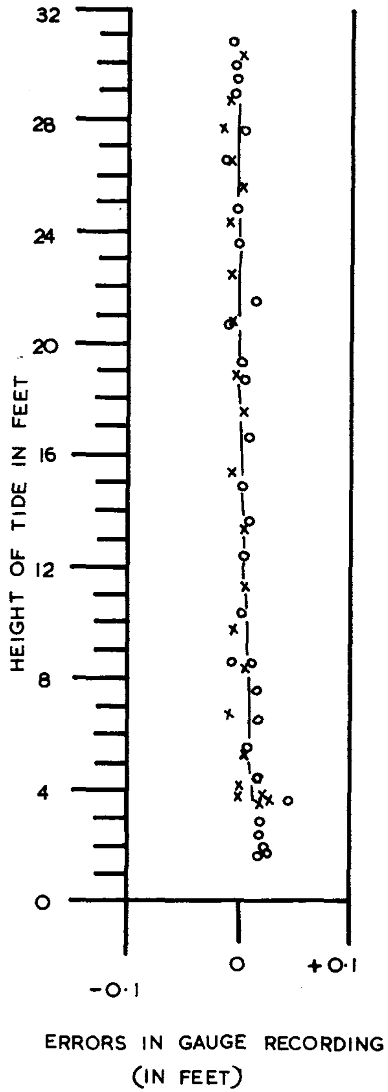
OTT GAUGE

FIG 5



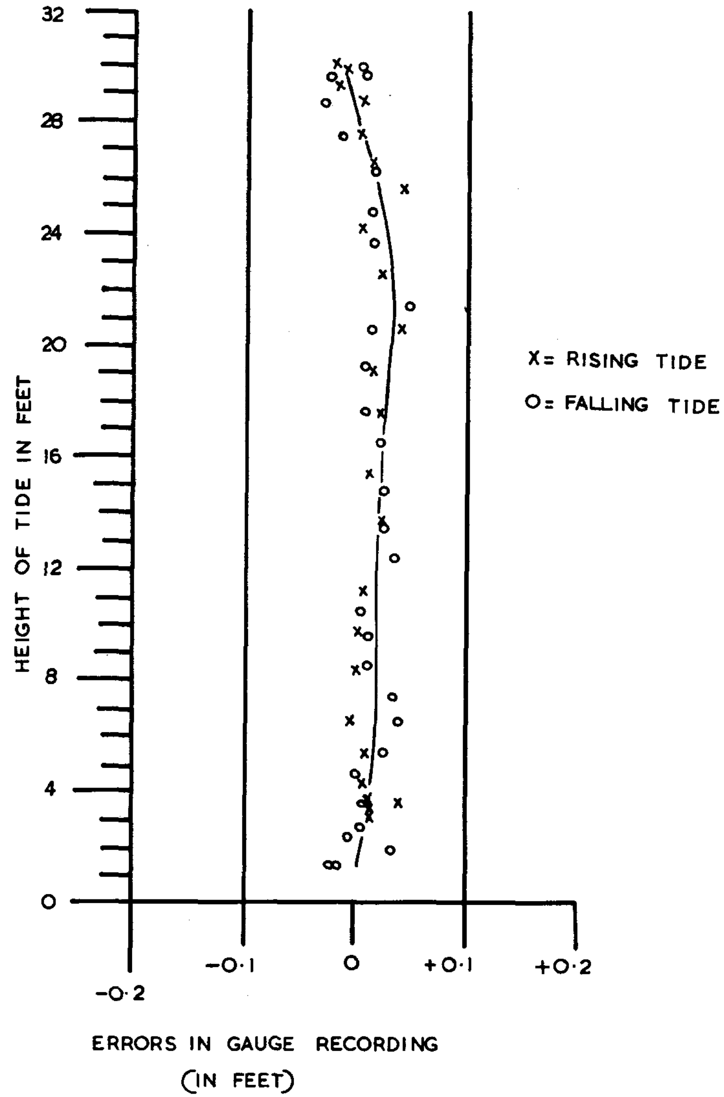
FISCHER & PORTER GAUGE

FIG 6

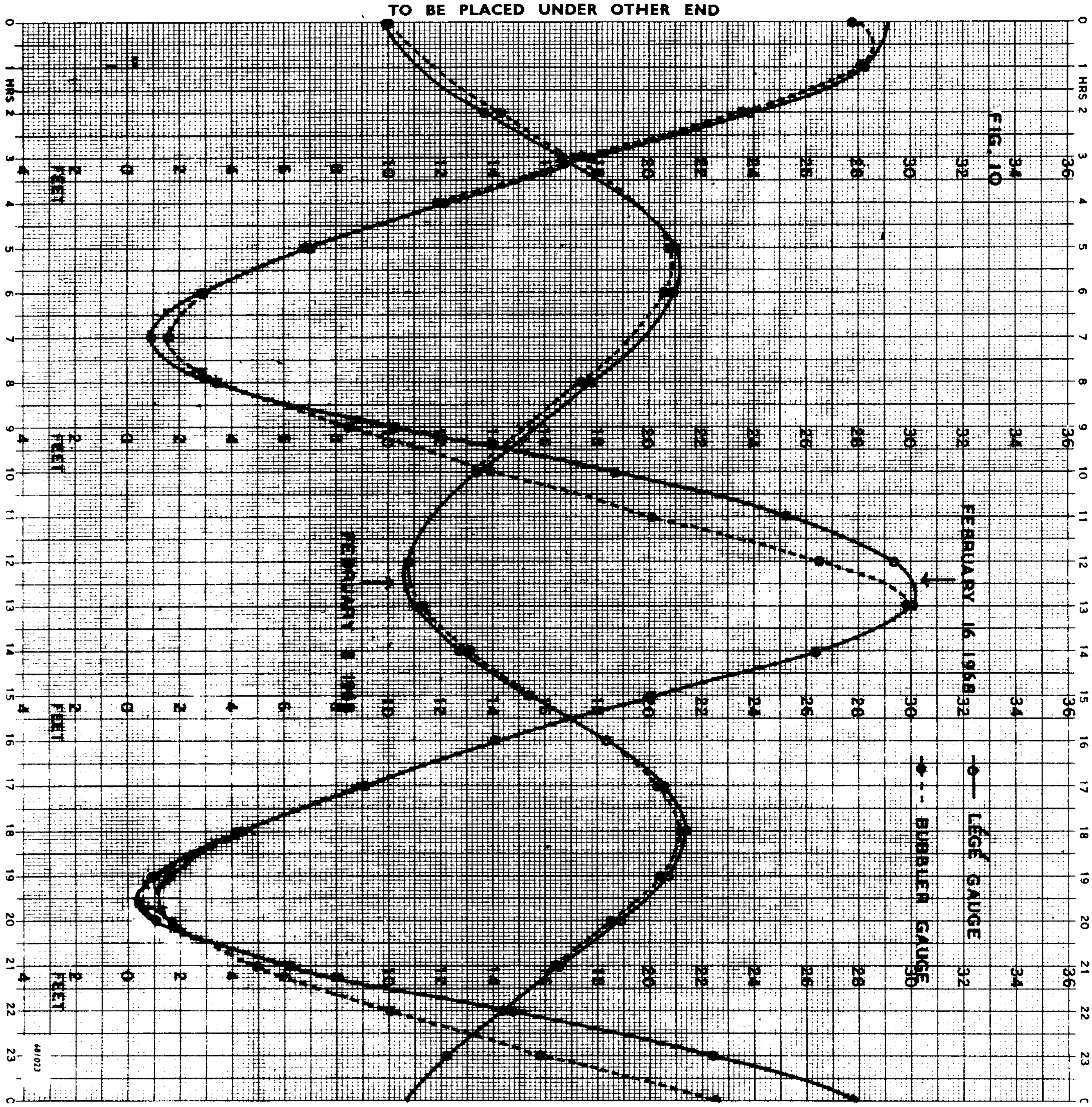


LÉGÉ GAUGE

FIG 7



TO BE PLACED UNDER OTHER END



NEGRETTI & ZAMBRA GAUGE JANUARY 30 1968

FIG 8

LINE SHOWS ERROR DUE TO DISCREPANCY BETWEEN DENSITY OF WATER CONTAINED IN WELL AND WATER DENSITY ASSUMED BY MANUFACTURERS.

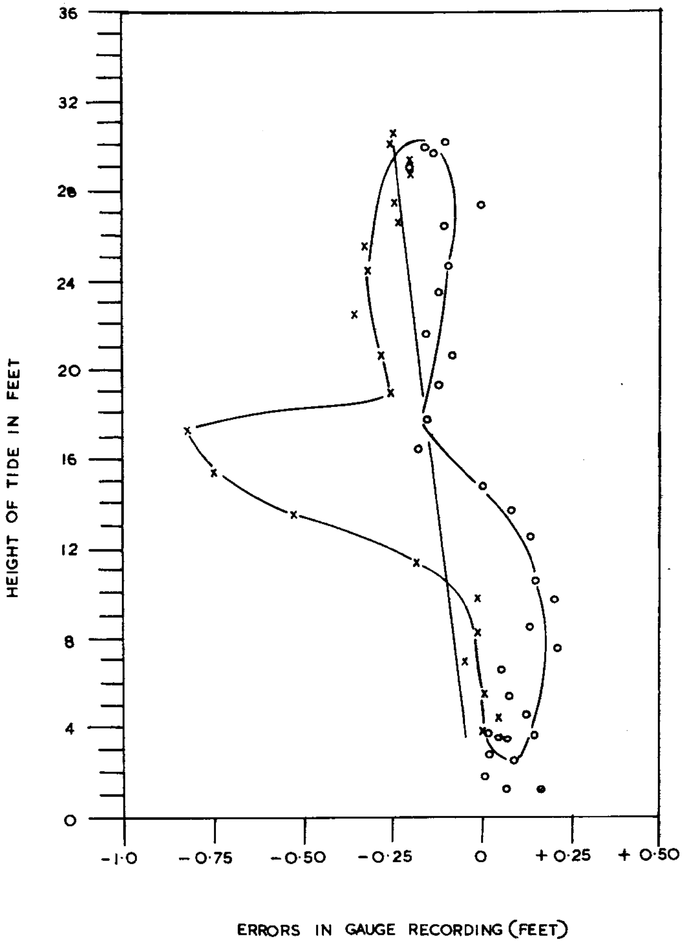
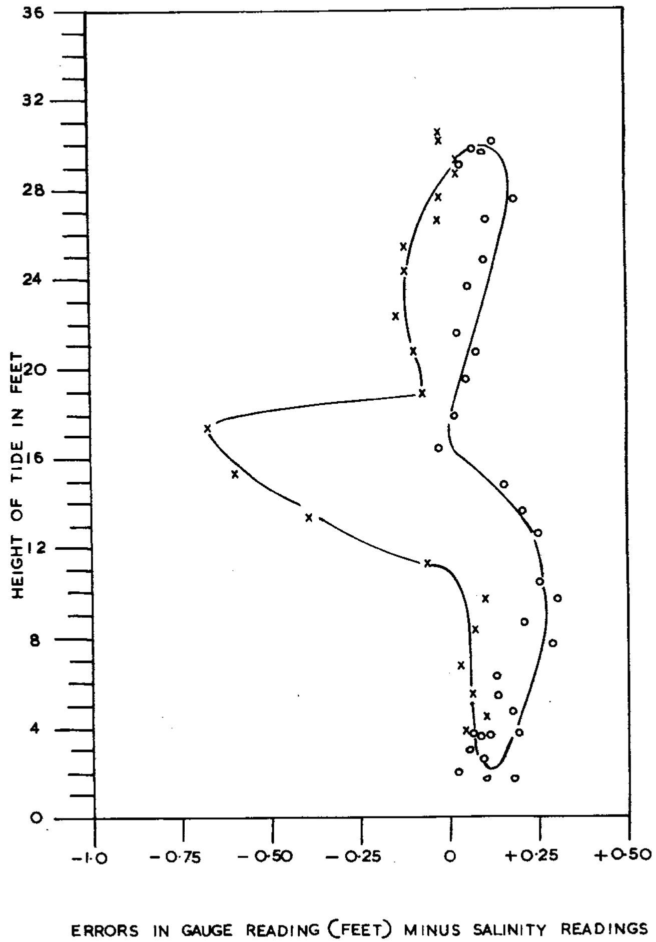


FIG 9

CORRECTED FOR ERRORS DUE TO WATER DENSITY DISCREPANCIES.



X = RISING TIDE. O = FALLING TIDE.