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THE BEHAVIOUR OF A STILLING-WELL IN THE PRESENCE OF PERIODIC DENSITY VARIATIONS

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G W LENNON

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institute of coastal oceanography and tides

NATURAL ENVIRONMENT RESEARCH COUNCIL

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

Many of our tide-gauges are sited in river estuaries where salinity variations may occur within the tidal cycle. In these circumstances the arrangement of the conventional tide-gauge well causes concern since it is unlikely that the sample of water contained within the well will be representative at all times of the open water. This note describes a brief investigation which has been made in this context of the behaviour of the tide-gauge well at Alfred Dock, Birkenhead.

The instrument used in this investigation was a probe designed to sense for both salinity and temperature. On September 2nd 1966, this probe was fixed inside the tide-gauge well at the time of low water at an elevation near to the well orifice. Throughout the period of the rising tide a continuous set of observations was made so as to monitor the characteristics of the water entering the well. The readings of temperature and salinity were converted into a measure of density and are plotted in this form in figure I against the height of tide in feet above Chart Datum (pecked line). It can be seen that the range of density observed on this occasion was 1•0157 at low water to 1•0212 at high water. At the time of high water the probe was raised through the water contained in the well in steps of 2 ft. and observations were made of the vertical profile. The latter is plotted as a continuous line in figure I against the height of the probe above chart datum. The evidence here is that although at the time of high water density is high in the open water, the sample contained in the well covers the complete range of densities experienced during the rising tide with the less dense low tide water at the top of the column. Moreover the two profiles described above, appear as mirror images of each other about a level approximating to mid-tide. The position is perhaps most easily appreciated by reference to the circular plots which display the same vertical well profile at high water plotted against depth using the right hand scale of figure I. These follow closely the time profile of density observed during the rising tide.

The mechanism is simply this. At low water the well contains little water and this is of low density and similar to the open water at this time. As the tide rises, the density of the open water increases and this water enters the well at its base and displaces upwards the lighter water already contained in the well. The process continues throughout the rising tide until at high water we find a continuous stratification over almost the complete density range experienced during the tidal cycle.

On September 19th, a similar test was made and this is particularly interesting in view of the anomaly which occurred between 10 and 15 feet on the rising tide. In figure II, the pecked line shows a reversal of the normal trend near this level when for a time, the water density decreased. The explanation of this feature is that at this point on the rising tide, the lock gates near to the tide-gauge were opened to release low density water from the enclosed dock into the river. After the pronounced disturbance which this incident caused the time profile rapidly resumed the normal trend. In spite of this anomaly, the vertical profile taken at the time of high water still mirrors the time profile as in figure I and the evidence of the opening of the dock gates is locked in the water column contained within the well some hours later. Only a minor modification is to be seen. The reversal of the density gradient creates instability which cannot be retained in the water column. This has now been replaced by a discontinuous feature in which, the density does not change through a 5 ft. section of the well column.

From the point of view of the observation of tidal elevations using a stilling-well the significance of this phenomenon is shown by figure III which shows the vertical density profile both inside and outside the well at the time of high water on September 19th 1966. The well is essentially a pressure device whereby the column of water above the orifice inside the well is balancing the pressure of the head of water above the orifice outside the well.

In fact g x density (outside) x elevation above orifice (outside) = g x density (inside) x elevation above orifice (inside).

At high water on September 19th the depth mean density (outside) = 1·0222
" " " " " " " " " " (inside) = 1·0181
The height of water surface inside well above orifice = 32·2 ft.

$$\therefore \text{elevation above orifice (outside)} = \frac{1{\cdot}0181}{1{\cdot}0222} \times 32{\cdot}2 \text{ ft.} = 32{\cdot}068 \text{ ft.}$$

This implies a difference in the level of the water surface inside and outside the well of 0·132 ft. so that irrespective of the performance of a tide-gauge recorder the well itself contributes an error which is negligible at low water but increases to a value in excess of 0·1 ft. at high water.

A similar calculation conducted upon the observations made on September 2nd shows a similar result.

At high water on September 2nd the depth mean density (outside) = 1·0215
" " " " " " " " " " (inside) = 1·0180
The height of water surface inside well above crifice = 31·8 ft.

$$\therefore \text{elevation above orifice (outside)} = \frac{1{\cdot}0180}{1{\cdot}0215} \times 31{\cdot}8 \text{ ft.} = 31{\cdot}691 \text{ ft.}$$

a difference of 0·109 ft.

The error amounts to 0·4% of the water head.

This feature must be present to a greater or lesser degree in all tide-gauges sited in estuaries where a significant chemical and/or temperature variation is present within the tidal cycle. Since the magnitude of the error is dependent upon the head of water above the orifice its significance will be roughly proportional to the range of tide.

It is interesting also to note that the float rests in water of constant density throughout the cycle so that there is no compensatory movement in the level at which the float rides in the water.

Elimination of this error is difficult. The alternatives are as follows:-

(1) one can attempt to correct the records of a conventional tide-gauge installation using a knowledge of density variations inside and outside the well.

(2) one can dispense with the stilling well and use a pressure transducer on the bottom in open water. This solution does not by-pass salinity problems and in fact may necessitate the continuous monitoring of the density profile.

(3) it may be possible to use other techniques of measurement in open water using resistance cables or capacitor chains which by-pass salinity problems but raise difficulties over the damping of short period surface waves.

The recommendation which I would like to make at the moment is that a further study of salinity variations be attempted and that this should include other 'A' class gauge installations, so that the problem may be assessed at each site. This procedure may make possible the solution of the problem via the first alternative listed above. Where research work justifies the elaborate correction process involved, this can be effected on present or past records. The ultimate solution in terms of refined instrumentation is thereby left open.

Appendix. *

Further to the tests described in T.I.I.R. No. 7 an investigation of the effect of salinity variations has now been conducted at two other tide-gauge installations in the Mersey.

The observations were made on December 1st 1966 and consisted simply of a pair of salinity/temperature profiles both inside and outside the well, first at Princes Pier and later at Gladstone Dock. The Princes Pier observations were made in the interval half to one quarter hour before high water and those at Gladstone, one quarter to half an hour after high water. The high water in question occurred at 1300 hrs. and its level was predicted at Princes Pier to be 27·5 ft. above datum. Due to severe weather conditions, viz. a barometric pressure 1·46 inches below normal and winds of 32 mph from W.S.W. gusting to 44 mph, recorded levels were appreciably higher than predicted. During the tests at Princes Pier, recorded levels were slightly in excess of 30 ft. above C.D. and at Gladstone slightly less than 30 ft. above C.D.

The salinity/temperature observations were converted to estimates of density and the profiles are shown in figures IV and V attached. It is immediately apparent that the density range inside the well at Gladstone Dock is very great which is rather surprising since this installation is some three miles downstream from Princes Pier. The Gladstone installation is, however, confined within the entrance to the dock system and it would appear that it is affected by land water to some extent.

The elevations of the well orifices are not known but it is reasonable to assume in both cases that an estimate of 5ft. below Chart Datum would be a reasonable one. On this assumption the depth mean densities of the upper 35 ft. of water were accepted in the model for the calculation of the elevation differential based upon a pressure balance about the orifice. The appropriate facts are as follows:-

AT HIGH WATER ON A 30 FT. TIDE

Princes Pier :

Depth Mean Density outside well above orifice = 1·0230
" " " inside " " " = 1·0179
Estimate height of water (inside) above orifice = 35 ft.
Elevation of water (outside) above orifice = $\frac{1{\cdot}0179}{1{\cdot}0230} \times 35$ ft. = 34·826 ft.
a difference of 0·174 ft. representing 0·5% of water head.

Gladstone Dock :

Depth Mean Density outside well above orifice = 1·0236
" " " inside " " " = 1·0175
Estimated height of water (inside) above orifice = 35 ft.
Elevation of water (outside) above orifice = $\frac{1{\cdot}0175}{1{\cdot}0236} \times 35$ ft. = 34·791 ft.
a difference of 0·209 ft. representing 0·6% of water head.

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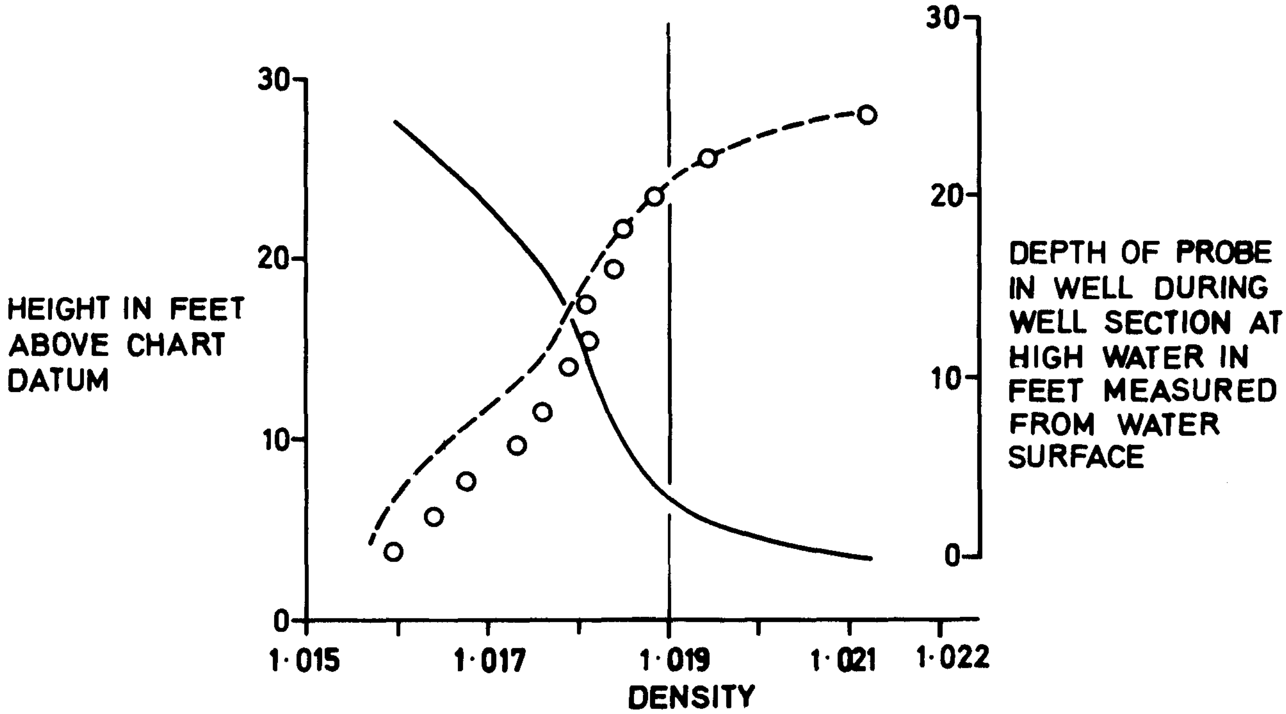
FIG. 1 2nd SEPTEMBER 1966



--- DENSITY MEASURED NEAR ORIFICE INSIDE WELL DURING RISING TIDE REFERRED TO HEIGHT OF TIDE ABOVE DATUM

— DENSITY PROFILE IN WELL AT TIME OF HIGH WATER REFERRED TO HEIGHT OF PROBE ABOVE DATUM

o DENSITY PROFILE IN WELL AT TIME OF HIGH WATER REFERRED TO DEPTH OF PROBE IN WELL (RIGHT HAND SCALE)

FIG. II 19 th SEPTEMBER 1966

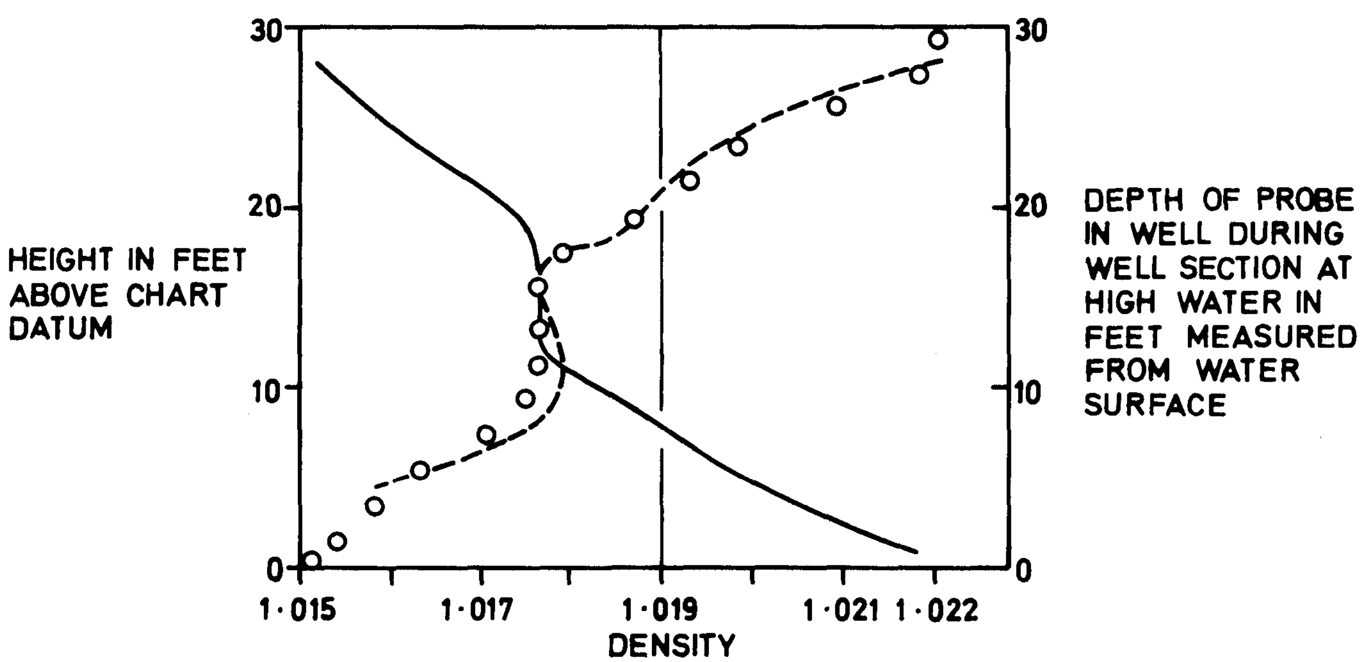
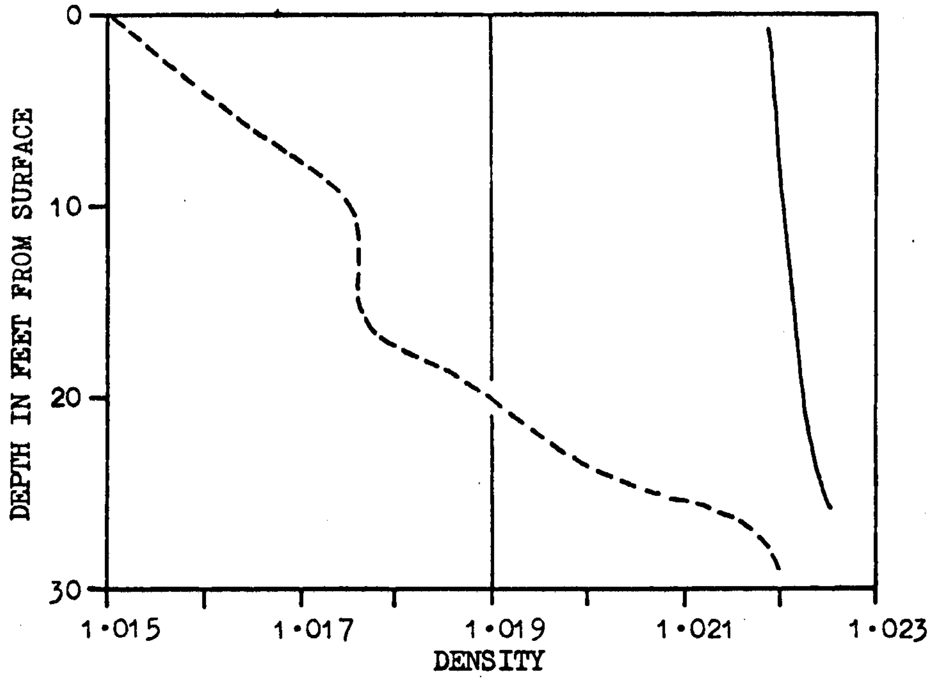


FIG. III 19th SEPTEMBER 1966



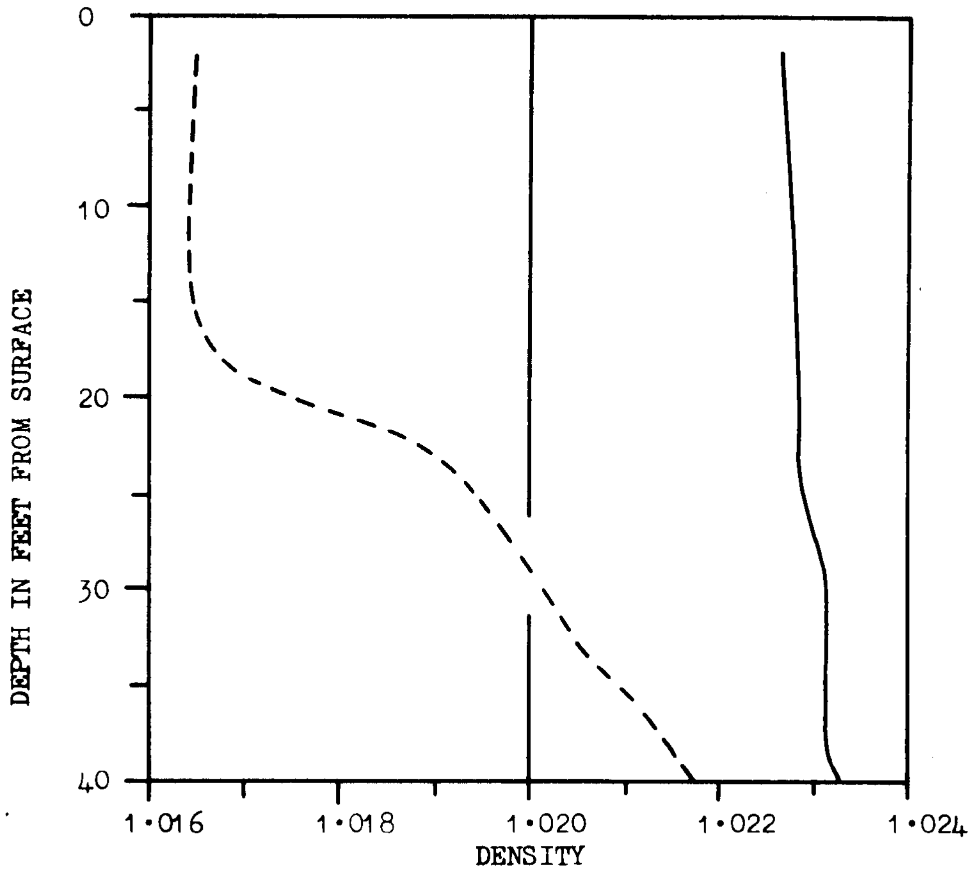
DENSITY PROFILE INSIDE AND OUTSIDE WELL AT HIGH WATER

- - - INSIDE

—— OUTSIDE

FIG IV

PRINCES PIER DECEMBER 1st 1966

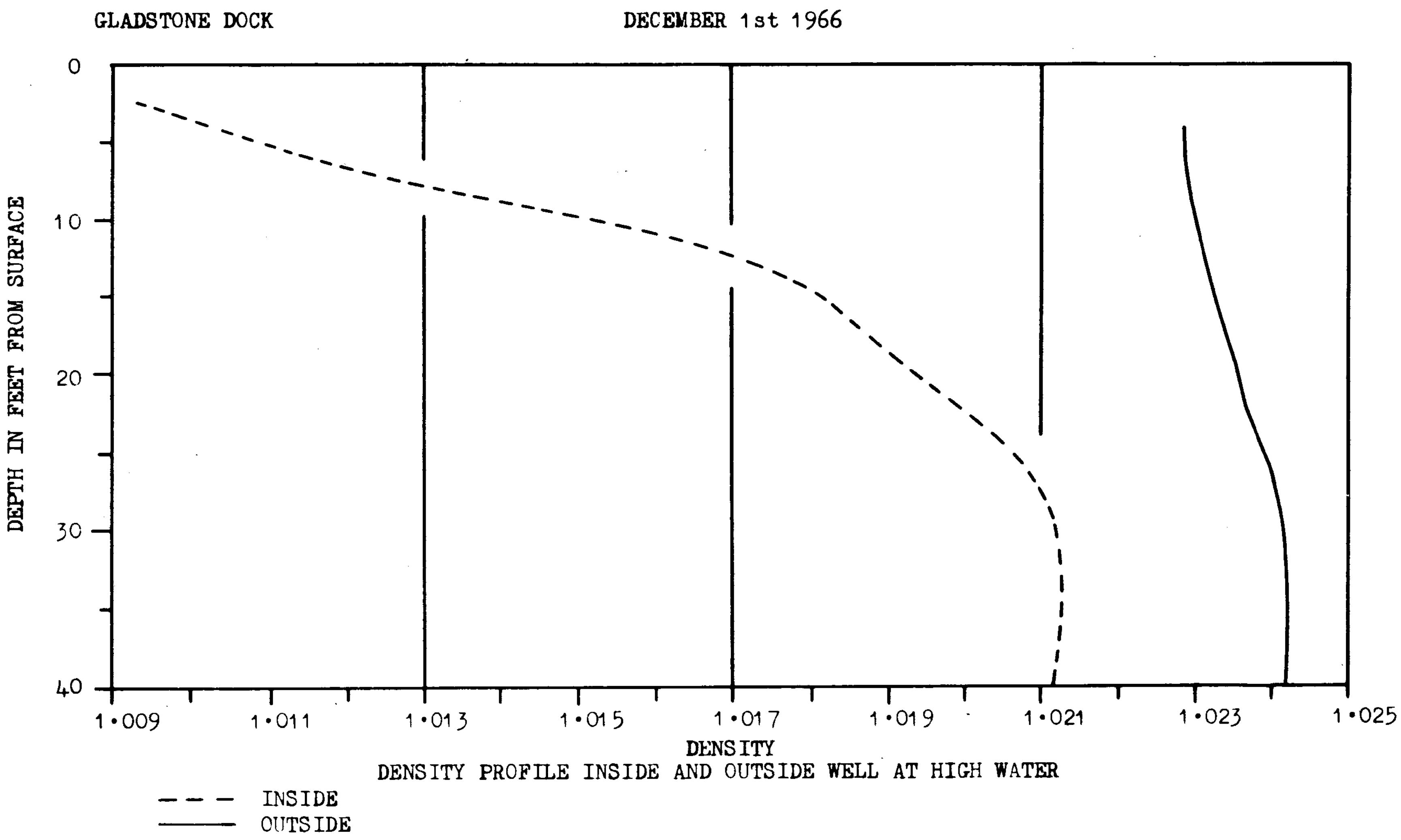


DENSITY PROFILE INSIDE AND OUTSIDE WELL AT HIGH WATER

- - - INSIDE

——— OUTSIDE

FIG V



DENSITY PROFILE INSIDE AND OUTSIDE WELL AT HIGH WATER