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DIGITIZING OF TORRES STRAIT TIDAL RECORDS

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Abstract

Procedures used in digitizing one year's records from each of six strip-chart tide recorders, using a manually-operated chart reader (Summagraphics) are described. Overall quality control and datum checks are discussed, and accuracy estimated. The complex nature of the tides in Torres Strait posed special problems in digitizing and subsequent checking.*

Introduction

In July 1973 this Division of CSIRO started the digitization of analogue records produced by five tide gauges operating in Torres Strait and one gauge at Booby Island in the Gulf of Carpentaria (Fig. 1).

The gauges in Torres Strait (Fig. 2) were installed by Decca Survey Australia Limited, under contract to the Australian Department of Transport, as part of an extensive investigation into tides and currents in and around Torres Strait. These gauges use float sensors in a stilling well to operate Fieldman** type 300M recorders (Fig. 3). The gauge at Booby Island, which was in existence some years before the start of this investigation, is a Leupold and Stevens Manometer Servo Water Level Sensor used in conjunction with a "bubbler" system.

All the gauges record sea level heights on paper moving at the rate of 9.6 inches per day, (0.4 in. per hour) with a vertical scale of 20 cm of water movement to one centimetre of pen movement, the vertical range across the paper being 5 metres.

The Torres Strait Gauges

Each of these gauges has an 8" diameter float operating in a 12" diameter well made from ½" thick black P.V.C. Each well is fitted with a removable brass plug in which a ½" diameter orifice has been drilled. This orifice, at the centre of a conical base at the bottom of the well, can be cleaned by lowering a cleaning tool or by a diver who can either clean the orifice with the plug in place, or remove the plug for cleaning at the surface.

* Made by Summagraphics Corporation, Connecticut, U.S.A.

** Made by Fieldman Instruments Pty Ltd of Sydney, Australia.

In practice it was found to be easier and faster to use a S.C.U.B.A. diver for inspection and cleaning because of the interference caused when lowering a cleaning tool inside the well. Many such inspections at each installation found little or no marine growth apart from a very thin film of gelatinous matter on the sides of the orifice.

With the given geometry of the wells, the response is linear for waves of tidal period down to twelth diurnal, while for waves of periods from 15-30 minutes there is attenuation in amplitude of the order of 5% and a phase lag of some 15°. Surface wind waves and swell are almost completely filtered out. A drainage test (Noye 1974) performed on the Goods Island well confirmed our calculated values of the response of the wells.

Inspection of the actual gauge records shows that oscillations with a period of some 5-10 minutes have been recorded, and that during periods of very rough weather in the north west monsoon season the record affected by surface waves, but was not heavily "embroidered" (Fig. 4).

The movement of the float in the well is transmitted to the recorder by a beaded wire passing over a pulley on the recorder to a small counter-weight on the other side. Some trouble was experienced during the early part of recording due to the beads becoming wedged in the holes in the pulley. This was quickly rectified.

The main features of the Fieldman recorder are obvious from Fig. 3. One unusual feature is the battery operated electric drive which proved to be most reliable in the field.

A persistent cause of trouble for some months was the lateral movement of the chart paper across the drive rollers. This resulted in a recorded curve whose base line was at an angle to the chart graticule and, quite often, in distortion of the time scale through wrinkling of the paper. Moreover, the angle between the base line and graticule varied as the paper tended to move back to the correct alignment after a certain lateral displacement was reached. This fault, which was corrected when new drive rollers were fitted to the recorders, caused some difficulty when checking digitized hourly heights by hand.

The chart rolls used at both the Torres Strait and Booby Island gauges are graduated across 25 cm of the paper to a scale of 20:1, giving a range of 0^m to 5^m, which has proved to be adequate during the 18 months of sea levels recorded so far.

The nominal time scale selected for the Torres Strait gauges was 9.6 inches per day to conform with the rate in the already existing Booby Island gauge. This rate gives 90 days of recording on rolls of paper 75 feet long.

A base line or zero pen is fitted to the gauges to detect lateral paper movement during recording. This base line pen is mounted 2.6 inches lower than the water level pen with the result that, at breaks in the record or at discontinuities, it is necessary to project the base line forward through these 2.6 inches. This point will be discussed further in comments on the digitizing process. Both the base line and main pens draw lines 3/4 mm wide.

Each of the Torres Strait gauges is visited at roughly fortnightly intervals to check the operation of the gauge and to make time and height checks. When making these checks the operator carefully marks the sea level record by moving the main pulley, causing the main pen to draw a short line across the trace. At the same time the heights of sea level on the visual gauge and in the stilling well are measured. Then the following information is noted on the record.

Gauge name.
Date and time (Eastern Australian Standard Time, Zone-10).
Visual gauge height (T.P.).
Stilling well height (SW).
Wind direction and speed.
Scend.

Notes are also made of any unusual event connected with the working of the recorder or operation of the gauge.

Booby Island

The gauge at Booby Island is a pneumatic pressure tide gauge operating through some 200 ft of pressure tubing to a gas outlet on a reef on the north west side of the island. At the outlet, the gas pressure is equal to the head of water when the gas flow is small. This pressure is measured by a mercury manometer which in turn has a servo mechanism fitted to drive a Leupold and Stevens Type A35 recorder. Sea level heights measured at this station are broadcast automatically to pilots of ships making the passage through the Straits.

The gas outlet was originally a bell shaped dome 15 cm in diameter and 8 cm high. This bell was removed in June 1975 leaving the orifice as a straight horizontal pipe of 1/8 inch internal diameter.

The Leupold and Stevens recorder uses the same paper and the same scales as the gauges in Torres Strait.

The station is operated by the lightkeepers on the island who visit the recorder four times a day to check the operation of the gauge and to annotate the record. The operators make the following notes at each visit.

Time (Eastern Australian Standard, Zone-10).
Date.
Wind speed and direction.
Height and direction of scend.
Sea level height on manometer scale.
Tide pole height.
Any unusual event.

Very little recording is lost through malfunction.

Bench Marks and Level Connections

The Division of National Mapping of the former Australian Department of Minerals and Energy established bench marks ashore near each tide gauge site. In the case of the Torres Strait gauges surveyors from both Decca Survey Australia Ltd and the Division of National Mapping levelled between the bench marks ashore, the zero of the visual gauge, and a reference mark at the top of each stilling well. In addition, the Division of National Mapping connected these bench marks and those at Booby Island to the Australian Levelling Network, using differences in height calculated from measured vertical angles and distances (Cook and Stead 1974).

At Booby Island differences in height were measured between the bench marks and the zero of the visual gauge.

The level differences between the bench marks and the gauges were remeasured from time to time during the course of the contract, that is between July 1974 and January 1976. The level connections will be referred to again in a section on datum corrections.

Digitizing of the Records

On receipt of the tide chart at Cronulla a list is made of the various gauge checks. This list shows both the stilling well and visual gauge checks together with the sea level at that time, carefully scaled from the chart. The differences, chart height minus visual gauge height and chart height minus stilling well height are found and listed.

These differences are then plotted against time (Fig. 5) to establish the difference between the zero of the recorder and the zero of the visual gauge, the latter being the standard for each gauge having been levelled and checked from shore bench marks.

The records are then digitized using a Summagraphics Data Tablet Digitizer operated by technical assistants of our data processing section. (The initial two months of the Torres Strait data were digitized on a "d-Mac" System at the Division of Wool Research at Ryde.). The Summagraphics system uses a crystal oscillator to count the delay between the injection of a strain-wave into magnetostrictive delay lines and the passage of this wave under a receiving coil (Fig. 6). This is done in both the X and Y directions thus providing a pair of coordinates (whose origin is at the lower left-hand corner of the table) each time the stylus is actuated by the operator. The coordinates are in inches and hundredths of an inch from the origin.

The very long continuous strip recordings produced by the Fieldman and Leupold and Stevens recorders are read in sections which the operator can conveniently handle on the reading table some four feet wide. Each of these sections of about four days recording is, before reading, related to previous and subsequent sections through an "origin statement" typed in on the keyboard, and two pairs of coordinates, one pair at each end of the section taken on the base line drawn by the recorder. This statement and the pairs of coordinates define the position and orientation of the section being read with respect to the recording table grid.

The stylus is then used to record pairs of coordinates at about every 1/3 inch (approx. 3/4 hour in time) increment in x, at abrupt changes of slope, and at tops and bottoms of curves. These coordinates, together with appropriate control statements typed in, are stored on magnetic tape in a PDP 11/20 computer. The tapes are edited to correct typing errors, reading errors, and to join several sets of data for further processing.

These edited tapes are sent to the CSIRO Cyber 76 computer in Canberra where, using a process of "double quadratic interpolation", the x-y coordinates are converted to hourly sea level heights which, in turn, are stored on magnetic tape in units of centimetres and tenths of centimetres.

ACCURACY OF THE READING SYSTEM

We have found the Summagraphics system to be an inexpensive, fast, and accurate means of digitizing analogue records produced by many different instruments in this Division.

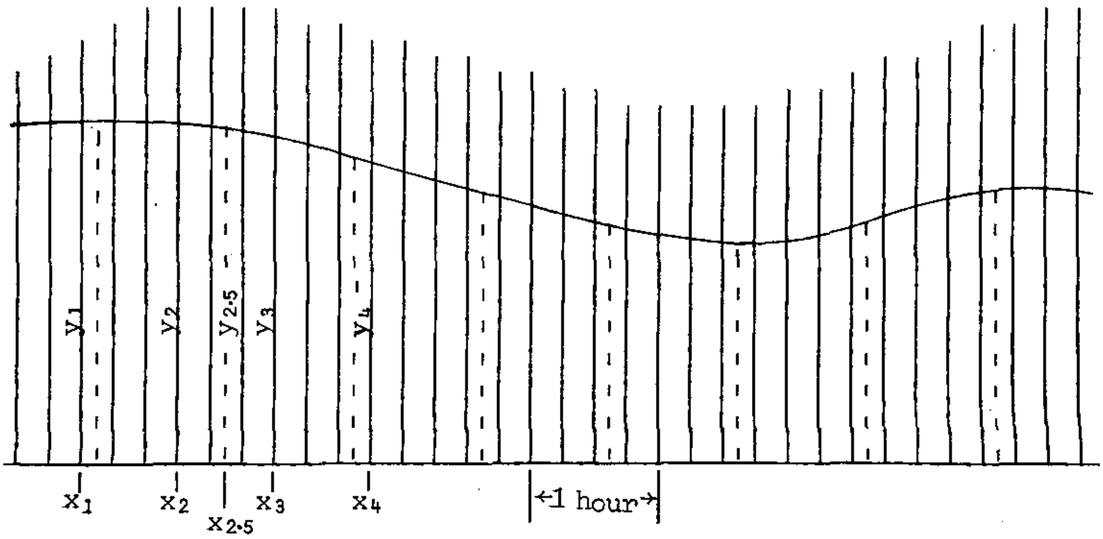
The precision of the system has been checked several times by using a perspex jig to describe circles on the reading table while the system is operating in "stream mode" where large numbers of coordinate pairs are read quickly and automatically.

After the coordinates have been produced, circles and ellipses are fitted to them and the scatter about these figures calculated. In addition, we compute the major and minor axes of the ellipses, the inclination of the ellipses to the recording table grid, the coordinates of the circles and ellipses and the radii of the circles. These tests have demonstrated that the system is capable of the resolution of 100 lines per inch claimed by the makers.

Numerous checks made by comparing the digitized data with scale measurement on the original record gives continuous assurance of the accuracy of the reading table coordinates.

We did experience some trouble due to loss of magnetic bias in the most used areas of the table grid. When the cause of the trouble was discovered the bias was quickly and easily restored.

PRECISION OF INTERPOLATION



In the process of "double quadratic" interpolation

$$y_i = \frac{y_a + y_b}{2}$$

where

$$y_a = y_1\frac{(x-x_2)(x-x_3)}{(x_1-x_2)(x_1-x_3)} + y_2\frac{(x-x_1)(x-x_3)}{(x_2-x_1)(x_2-x_3)} + y_3\frac{(x-x_1)(x-x_2)}{(x_3-x_1)(x_3-x_2)}$$

$$y_b = y_2\frac{(x-x_3)(x-x_4)}{(x_2-x_3)(x_2-x_4)} + y_3\frac{(x-x_2)(x-x_4)}{(x_3-x_2)(x_3-x_4)} + y_4\frac{(x-x_2)(x-x_3)}{(x_4-x_2)(x_4-x_3)}$$

Here x_1, x_2, x_3, x_3, x_4 are distances along the x or time axis (approximately 3/4 hour apart) and y_1, y_2, y_3, y_4 the height of the sea level curve at these points. From the above expressions it can be shown that,

$$y_{2\cdot 5} = -.0625y_1 + .5625y_2 + .5625y_3 - .0625y_4$$

We used this expression to check the accuracy of the interpolated value of y at $x_{2\cdot 5}$ against a scaled value of y at $x_{2\cdot 5}$. To make this comparison we used part of the Turtle Head chart during a period when the tidal record displayed abrupt changes of slope (Fig. 7).

Four values of x were selected at an interval of 3/4 hour as in the digitizing process, and the value of y scaled at these points. We then calculated $y_{2\cdot 5}$ and compared it with the scaled value of y at $x_{2\cdot 5}$.

In 15 cases investigated the difference between the calculated and scaled values varied between 0.2 cm and 4 cm of water level with 13 values being less than 2 cm. In the other two cases where the differences were 3 cm and 4 cm, $y_{2\cdot 5}$ was at a sharp change of slope.

Thus, digitizing and interpolation based on coordinates read at 3/4 hour intervals should not produce errors greater than two centimetres if the operator also reads coordinates at abrupt changes of slope.

CHECKING THE HOURLY SEA LEVEL HEIGHTS

Each hourly sea level height is checked for error by applying a smoothness test to the stored heights. This checking program (Lennon 1965) computes three different interpolated values of tide height at time t, based on the measured height both before and after t. The difference between observed and interpolated heights are defined as follows

$$T_1 = \frac{1}{6}\left(-h_{t-50} + 4h_{t-25} + 4h_{t+25} - h_{t+50}\right) - h_t$$

$$T_2 = \frac{1}{6}\left(-h_{t-2} + 4h_{t-1} + 4h_{t+1} - h_{t+2}\right) - h_t$$

$$T_3 = \left(-.0049h_{t-7} + .0410h_{t-5} - .1709h_{t-3} + .6836h_{t-1}\right.$$

$$\left. + .5127h_{t+1} - .0684h_{t+3} + .0068h_{t+5}\right) - h_t$$

Here h is the stored sea level height at hour t, and T a limit, which if exceeded, causes that height to be printed together with the values of the height calculated by the above formulae. The differences between the stored sea level height and the calculated heights are also printed.

The limit for each T was originally set at six centimetres, but when used with this limit, the checking program (CHECKTIDE) produced a very large output in which some 60 values of sea level per station per month were questioned. Despite the large amount of time involved each flagged value was checked by hand against the original record. Another run of the program was then made using the same data, this time with the limit set at 10 cm. On checking the output we found that hourly values questioned when using a 6 cm limit and accepted when the limit was 10 cm, had all been found to be correct when checked against the original record. Thus the flagging of these values at the 6 cm limit was due to the inability of the CHECKTIDE expressions to cope with the extraordinary nature of the tidal curve in Torres Strait (Fig. 7). Raising the limit to 10 cm decreased the output but still left a very large number of heights to be checked, approximately one value to be checked in each 48 hours of stored data.

To make such checks by hand it is necessary to measure time and height at the same scale as that used in the digitizing programs. Thus, to check any one height, it is necessary to establish the rate, in inches per hour of the pen movement along the paper. This is done by measuring along the base line, the precise distance between the time checks made in the field before and after the hour in question. This distance, when divided by the number of hours which elapsed between the time checks, will give the rate or time scale. This rate is considered to be uniform between checks if it agrees with the previous and subsequent rates within 5 minutes per day. If there is a difference in rate, the cause must be sought.

Having established the rate, in inches per hour, of pen movement, it is now possible to calculate the distance from a time check to the hour in question and then, to set out this distance along the base line.

In practice, if the rate is constant and close to the nominal rate and if the base line coincides with the graticule, it is sufficient to measure by scale along the graticule lines to establish the rate and to set out the distance to the hour in question. Again, given these circumstances, it is sufficient to set out only midnight and midday of a particular day and to measure to all other hours required on this day from these two points at the nominal rate. For this latter purpose we use a clear plastic scale graduated in hours and quarter hours at the nominal rate.

Having set out on the tide chart the hours in question, the distance between the base line zero and the sea level trace is measured in centimetres to establish the sea level height at that time. The distance in centimetres is converted to a sea level height using the nominal 20 cm to 1 cm scale factor. This procedure is followed each time a height is to be checked against a height established by the digitizing process.

If there is agreement between the digitized hourly height and the hand scaled value this height is, of course, accepted. However, we try to establish the reason for the "rejection" of this value by the CHECKTIDE program. This has always been found to be due to the inability of the CHECKTIDE program to follow the very complex tide curves.

If there is not agreement then, after checking, the hand scaled value is accepted and reasons sought for the error in the digitized value.

It has seldom been possible to establish the direct cause of incorrect hourly values of sea levels but, in the majority of cases where the error was less than 5 cm, we have found that the error was probably an interpolation error due to insufficient coordinate points being selected to follow a complex curve.

Occasionally we have found hourly values which are wrong by some 10-20 cm. We have not been able to establish positively the cause for these errors but we suspect that they are due to either:

(a) two or more coordinate points being inadvertently taken at very close intervals of x. This could be expected to cause large errors in one or both of the interpolation steps;

(b) loss of magnetic bias in the magnetostrictive delay lines.

It is important to note again that when reading and checking these records, we use the line drawn by the base line pen on the recorder as the zero for heights. In many cases, due to lateral movement of the paper, this line does not coincide with the graticule printed on the chart paper and is not parallel with it.

In these cases, when checking by hand, it is necessary to scale heights from this base line and perpendicular to it. In addition, in the case of records made by the Fieldman recorder, where changes of slope are present in the base line, it is necessary to project these changes forward by 2.6 inches (6½ hours), thus bringing them opposite the position of the main recorder pen.

Datum Corrections

The plots of chart height minus visual gauge height and chart height minus stilling well height (Fig. 5) are assessed from time to time as new information is added. This assessment is made to give a measure of the difference between the zero of the automatic gauge and the zero of the visual gauge, the latter being the standard for each installation.

In the case of the 5 Torres Strait gauges we have, so far, made no correction to the hourly heights although there is some evidence that datum changes of less than 2 cm occurred at Turtle Head and at Goods Island.

In the case of the Booby Island gauge we made several block alterations to the digitized data to correct for changes in the setting of the recorder zero and in the level of the zero of the visual gauge.

Levelling checks made in March 1975 disclosed that the gauges supporting structures at both Goods Island and Twin Island had subsided by some 2 cm. We have made no allowance for this alteration to the level of both the automatic and visual gauges.

Conclusion

We consider that the digitizing process together with the checks made, has produced hourly sea level heights which are within 2 cm of the height given at that time by the recorder pen. This accuracy meets the requirement of the Department of Transport that "Tidal height shall be recorded continuously with an instrumental accuracy of .02 metres. Hourly height values to be read from the records are required to have an overall accuracy of ±.05 metres".

It should be noted that we have so far applied datum corrections only to the Booby Island sea level heights, and that therefore a systematic error will be present in the hourly heights of any Torres Strait gauge whose datum (relative to the tide gauge bench mark) has altered.

References

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Lennon, G.W. (1965). The treatment at hourly elevations of the tide, using an IBM 1620. *Int. Hyd. Rev.* 42, 125-48.

Noye, B.J. (1974). Tide-well Systems III. Improved interpretation of tide-well records. *J. mar. Res.* 32, 2.

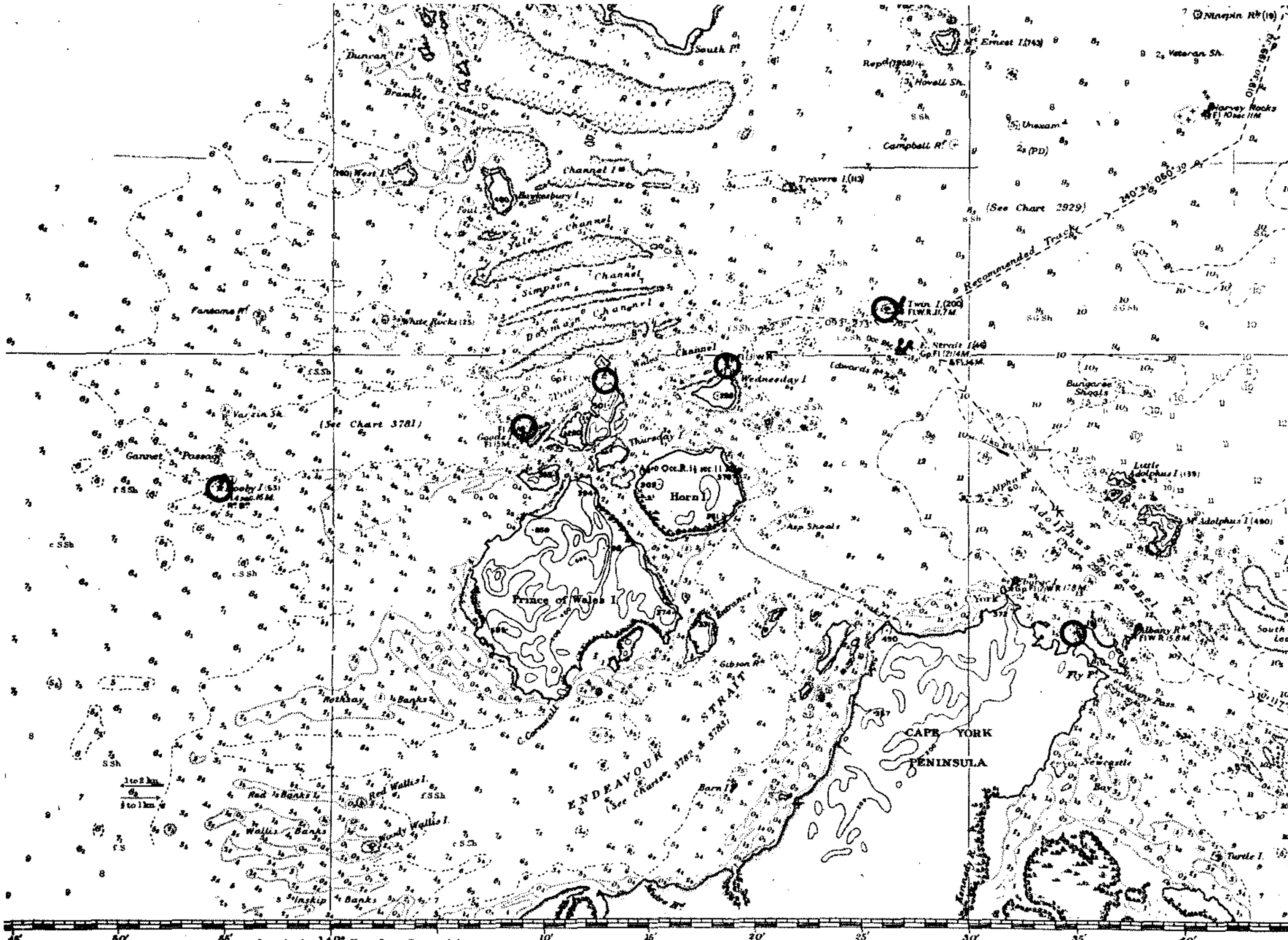

Fig. 1. Part of Chart BA2321, Torres Strait and Approaches, showing positions of Tide Gauge Stations circled.

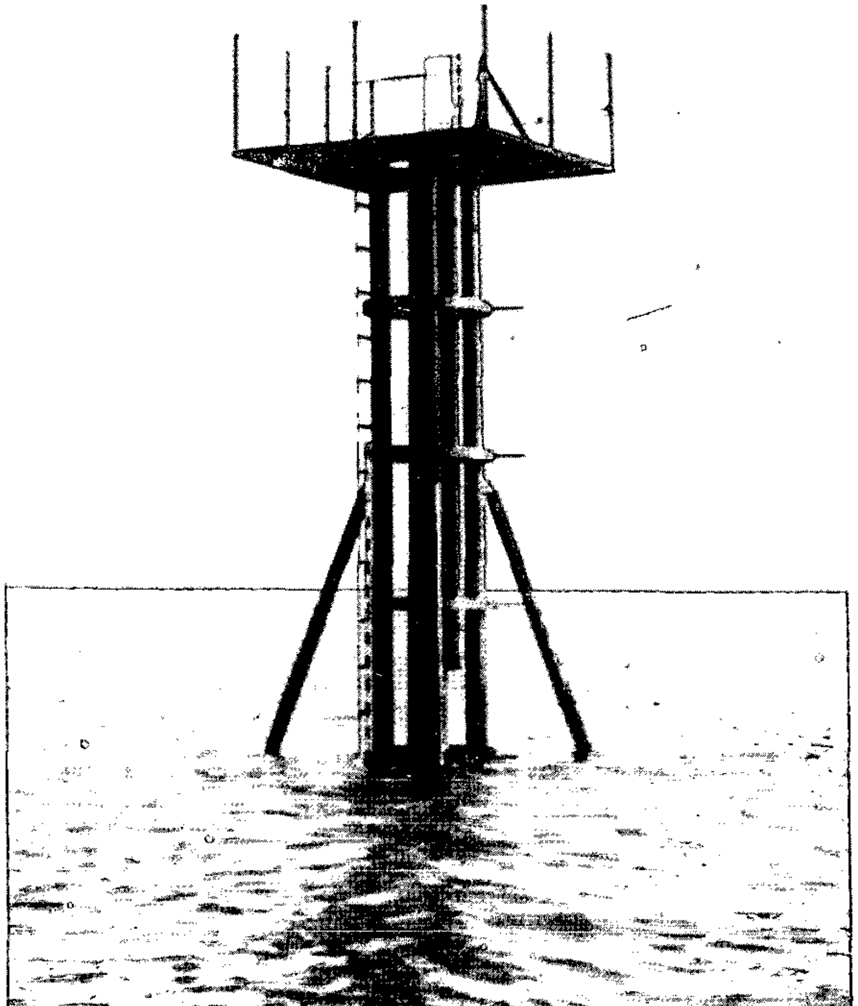

Fig. 2. Tide Gauge Structure off Goods Island.

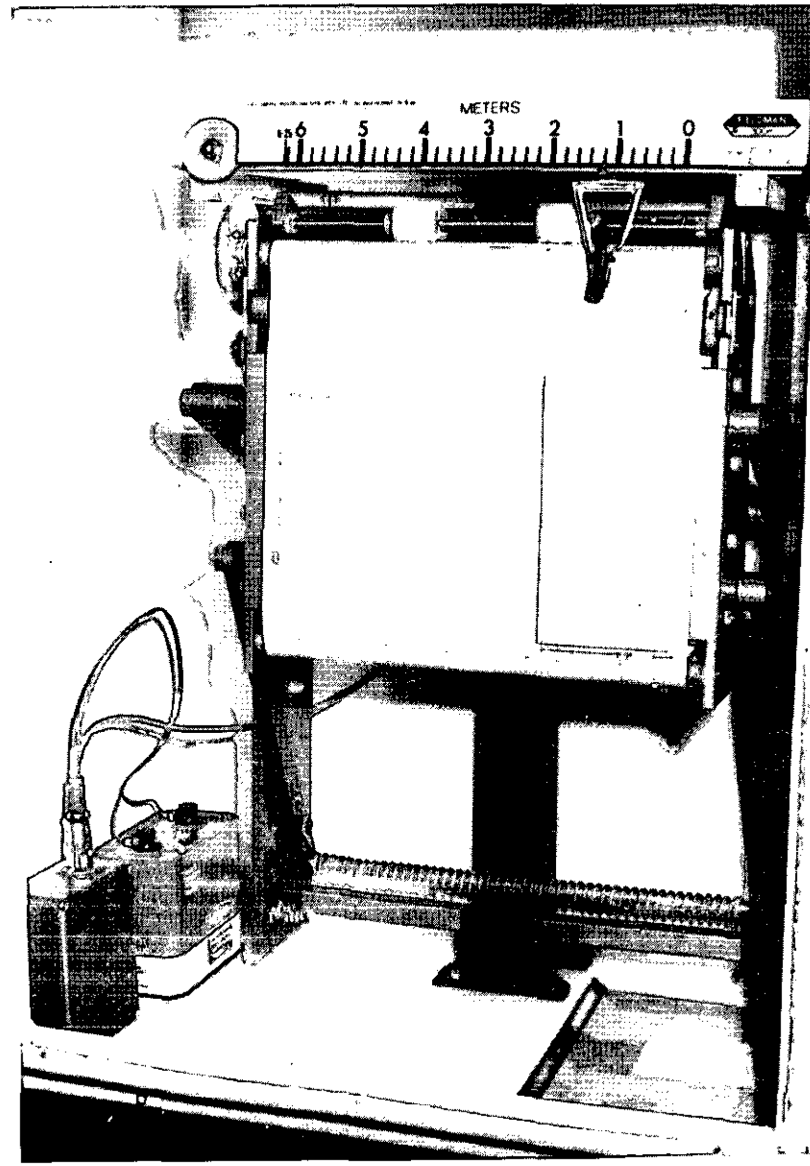

Fig. 3. Fieldman Recorder Type 300M.

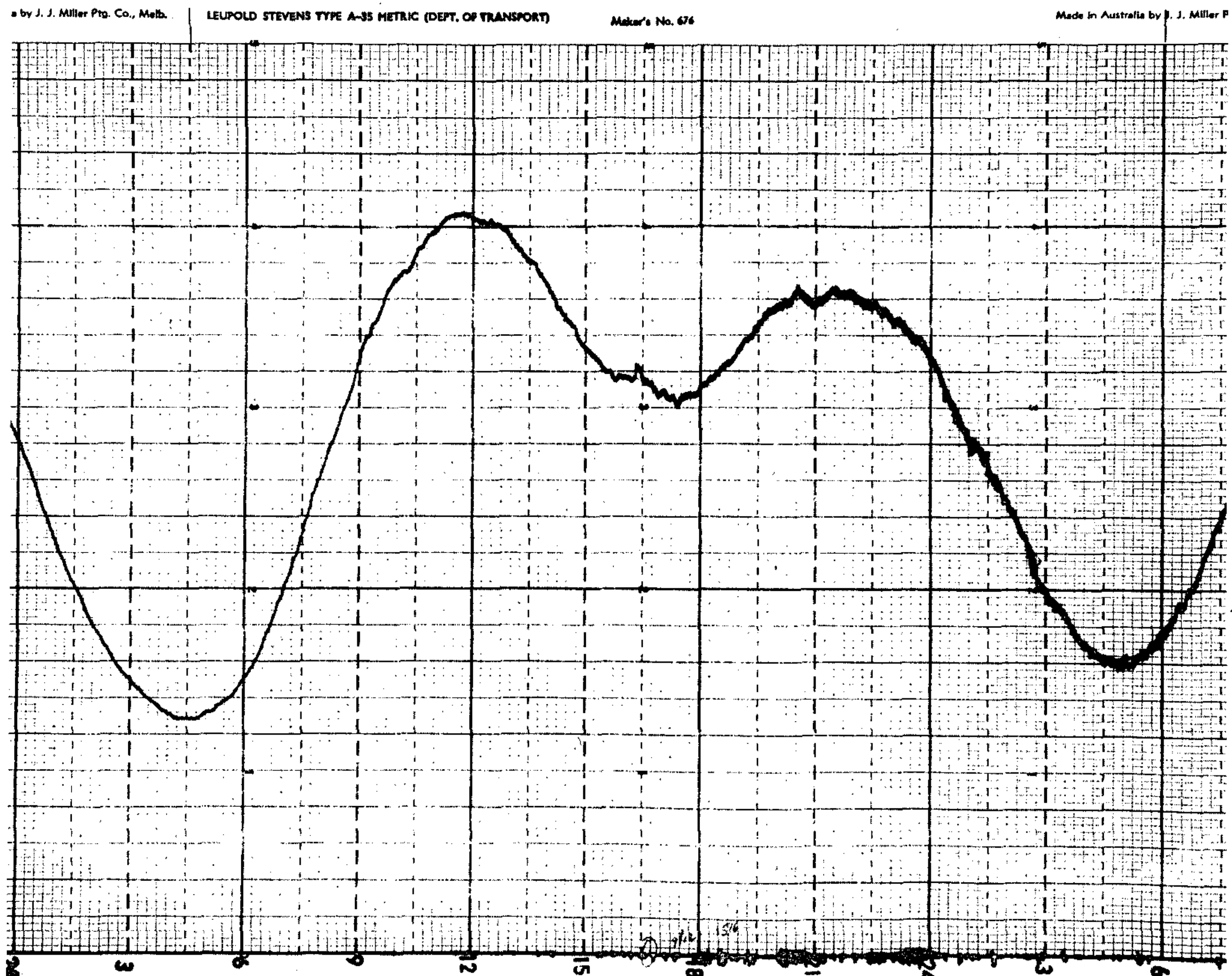

Fig. 4. Example of recording from Goods Island gauge showing thickening of trace due to surface waves 1-2 metres high.

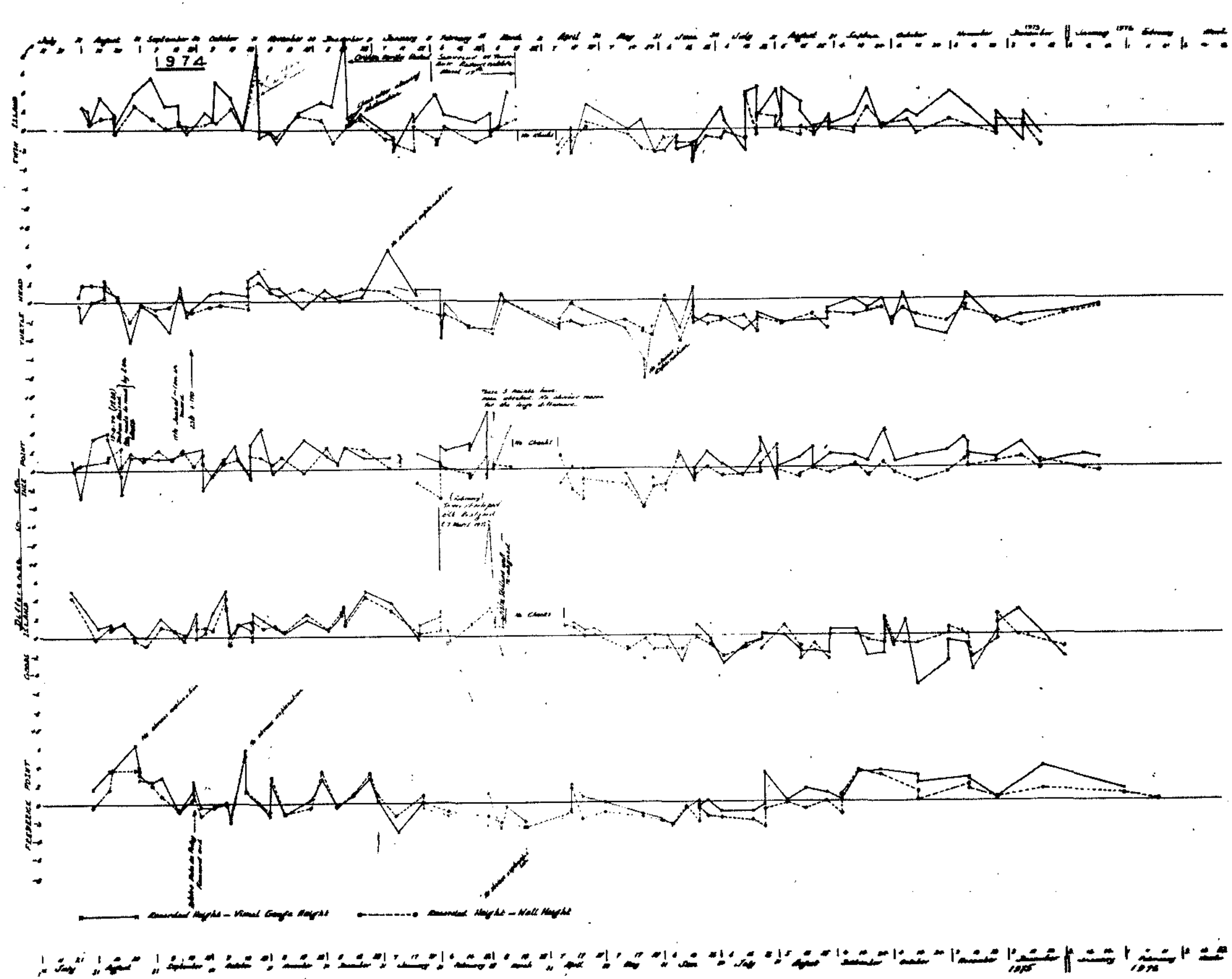

Fig. 5. Graphs showing recorded height — visual gauge height and recorded height minus stilling well height.

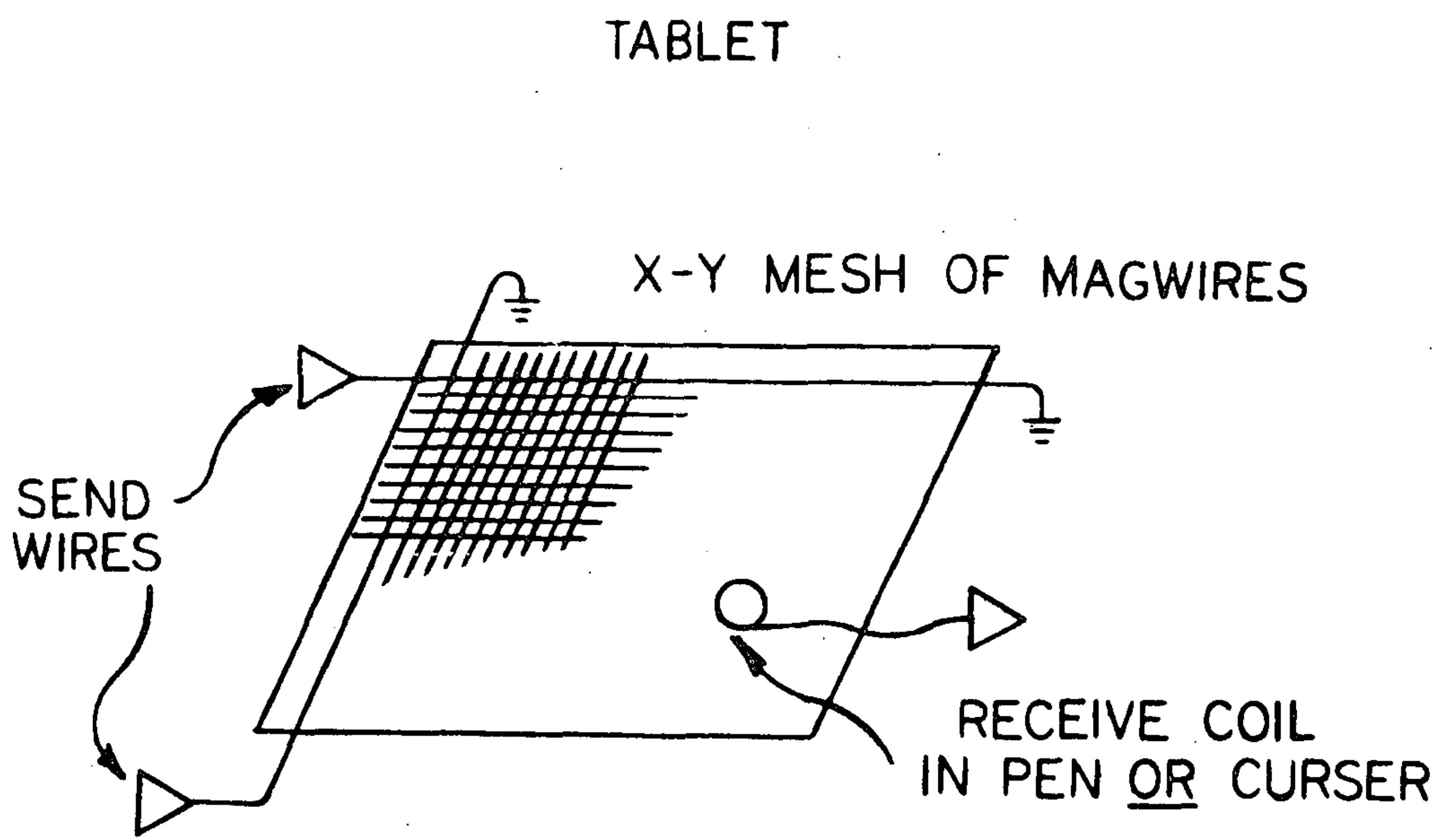

Fig. 6. Diagram showing X-Y mesh in Summagraphics Data Tablet Digitizer.

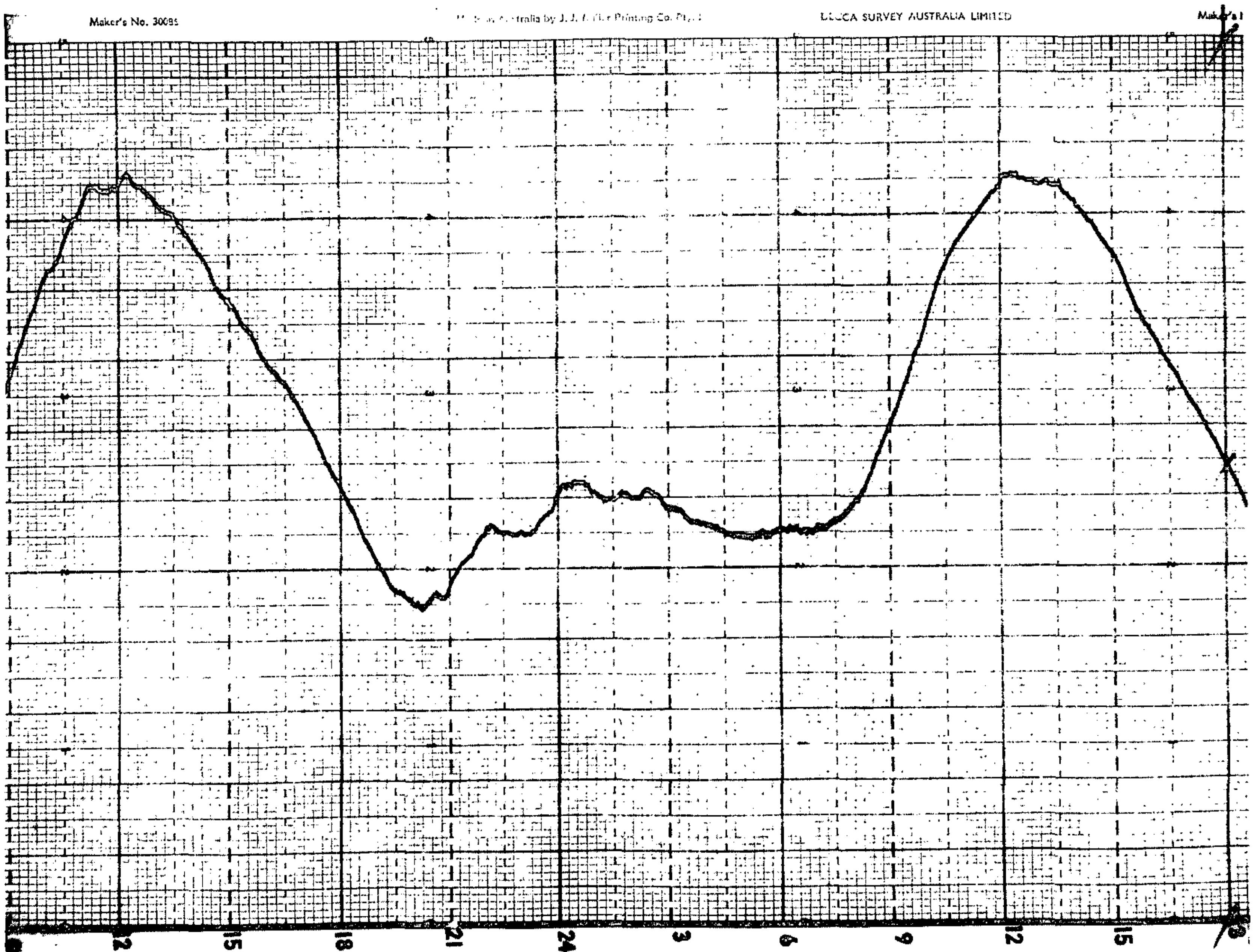

Fig. 7. Example of recording from Turtle Head gauge showing abrupt changes of slope.