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WATER-LEVEL RESPONSES TO A SEMI-DIURNAL SINUSOIDAL WAVE EXCITATION IN THE NORTH SEA

- An interpretation of tidal patterns -

S. Ishiguro

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NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Wormley, Godalming,
Surrey GU8 5UB
(042-879-4141)

(Director: Dr. A. S. Laughton)

Bidston Observatory,
Birkenhead,
Merseyside L43 7RA
(051-653-8633)
(Assistant Director: Dr. D. E. Cartwright)

Crossway,
Taunton,
Somerset TA1 2DW
(0823-86211)
(Assistant Director: M. J. Tucker)

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21 pages, 15 diagrams

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CONTENTS

ABSTRACT

The computed responses of the water-level to a sinusoidal excitation with the semi-diurnal period at a single point in the North Sea have been described, taking the excitation point in the northern entrance and southern entrance of the sea separately, with the earth rotation from west to east and east to west, i.e. four cases in all. Although the first aim of the computation is to test the model itself, the results are also useful for interpretation of the tidal patterns in the North Sea, indicating the degrees of contribution of some geophysical factors to the patterns.

1. INTRODUCTION

Although the new electronic model for tides and storm surges can be applied to most continental-shelf seas, this has been set to the sea around the British Isles at the moment (Ref. 5). In order to test this setting, the model is excited by a sinusoidal wave at a single point (a grid in the model), as a forced oscillation, and its responses at all the grids were obtained. This test method has advantages:-

A Both the excitation and responses can be represented simply by an amplitude and phase at each grid, when the period is kept in a certain value.

B Since the excitation is non-directional at its source, the wave propagation is influenced only by the model parameters representing the topography of the sea, Coriolis force and frictional forces, so that any abnormalities of the model can easily be detected.

The tests were carried out in the following four cases:-

Case 1 Excitation at a grid in the Strait of Dover, with the earth rotation from west to east;

Case 2 The same as above, but with the earth rotation from west to east;

Case 3 Excitation at a grid off the Orkney Islands, with the earth rotation from west to east; and

Case 4 The same as above, but with the earth rotation from east to west.

The period of the excitation was kept constantly to 12.0 hours (1.20 milli seconds in the model). This period represents all the semi-diurnal tidal components approximately in the tests, rather than the S_2 tide alone.

The model was run 9 times setting to the above four cases. During the first 5 runs, all the abnormalities in the model have been detected and rectified. The causes of the abnormalities which were all instrumental have been described in a separate paper (Ref. 6), together with the methods of preventing them.

Described in this paper are the results of the last four runs, each of which represent Case 1 to Case 4 respectively. These are useful for interpreting the patterns of semi-diurnal tides observed in the North Sea.

2. HISTORY

After it has been confirmed that a model can reasonably simulate a real tide/surge phenomenon, if a condition given to the model is artificially modified, the result would show the degree of contribution of the condition to the phenomenon. The author has come across few published works in which this technique is intentionally applied to a tide/surge phenomenon, although the adjustments of some model parameters, in order to obtain a good agreement of a model, is common.

In order to interpret the tidal patterns in the North Sea, the author used this technique in his earlier work (1961), including some artificial cases:-

1 Waves through the northern entrance of the sea alone, with its southern entrance opened;

2 Waves through the southern entrance of the sea alone, with its northern entrance opened;

3 Waves through the northern entrance of the sea alone, with its southern entrance closed; and

4 waves through the two entrances of the sea, without the earth rotation.

Although the above four artificial cases were analysed with the diurnal and semi-diurnal components, only the results for the latter have been reproduced in Appendix 3, together with an amplitude/phase diagram of the M_2 tide in the North Sea computed by the author in 1961. For the comparison of the last diagram, a similar diagram based on observational data (arranged by the German Hydrographic Office, 1941) is shown in Appendix 2.

This paper will add more information to the above-mentioned work, with an improved resolution and a wider sea area. The cases with the reversed direction (east to west) of earth rotation are new, and show the effect of earth rotation in this subject more clearly, while the earlier work includes a case where the earth rotation is ignored.

3. OUTLINE OF THE MODEL SETTING

The model is an electronic system by which the tide/surge hydrodynamic equations, including the atmospheric pressure and wind on the water surface and Coriolis force, can be solved quantitatively. This technique offers the solution of the dynamic equations without a step-by-step process (which is inherent in a digital technique) and overcomes problems of computational instability due to such a process. The technique also facilitates speedy computation, e.g. 20 milli seconds for a 10-day storm surge.

The principle of the electronic model has been described in Ref. 1. The basic hydrodynamic equations and equations from which the model parameters have been derived have been described in Ref. 4. The model scheme and the values of its parameters have been described in Ref. 5.

The modelled area covers most of the continental-shelf sea around the British Isles, but the analyses in this paper are limited to the North Sea and the north-west part of Scotland. Throughout the whole model area, a uniform grid size of 50-km square is used.

The undisturbed water depth of each grid has been obtained by averaging all the available data in the grid on the Admiralty Depth Charts. Appendix 1 shows the undisturbed water depth in the North Sea obtained by smoothing such values for the grids, and this indicates the bottom topography to which the model has been set.

The modelled area is terminated in its northern part along the 210 m water-depth line, but including the Norwegian trench. An 'open-boundary network' (Ref. 4) is used for such a boundary facing to the open sea. The Skagerrak is represented temporarily for this test with another open-boundary network, although this will be more precisely modelled later. A similar temporary boundary is applied to the southern part of the Strait of Dover in this test.

The bottom friction in the model is linearised by Equation 18 in Ref. 4 with $r = 0.24$ cm/sec. However, for grids covering steep bottom slopes, the values of r are adjusted experimentally so that the frictional force and the Coriolis force balance (Ref. 6).

Note, the sign of the Coriolis force, i.e. the direction of the earth rotation in the model, can be reversed simply by reversing the W-E terminals of each grid, taking less than half an hour for the whole model. This is, at the same time, a simple method of testing the facility for the Coriolis force in the electronic model.

4. RESULTS

4.1 Representation

Fig. 1 to Fig. 4 (each figure consists of two diagrams) show the results obtained for Case 1 to Case 4 (page 3). A figure number with suffix A shows an amplitude diagram, and that with suffix P shows a phase diagram. The position of the excitation source is indicated by an arrow in each diagram.

In each amplitude diagram, the amplitudes are indicated by equal-amplitude lines, with the scale of percentage of the amplitude at the excitation source. Note, intervals of equal-amplitude lines are not uniform.

In each phase diagram, the phase angles of responsed waves referred to the wave at the excitation source are indicated by equal-phase lines, with intervals of 30 degrees.

The excitation is sinusoidal, and its period is 12.0 hours throughout all the diagrams.

Data is not shown for an area where the responsed amplitude is less than 0.5%.

It is recommended that a set of amplitude and phase diagrams be used, which have been printed on successive pages, by holding them up to the light.

4.2 Cases 1 and 2

In Cases 1 and 2, the excitation point is taken on Grid E9 (55.0°N, 2.0°E approx.; off Orkney). The waves generated at this point propagate less directionally near the source, forming an approximate circle. They soon change into approximate lines, and propagate into two areas: the North Sea and the sea around the north-west of Scotland.

In Case 1 where the earth rotation is west to east, the waves entered into the North Sea form a similar amplitude/phase pattern to that produced by a semi-diurnal tide (e.g. M_2), including the amphidromic point off Germany. Note the well known amphidromic point near the Strait of Dover is missing from this diagram.

The southwards propagation of semi-diurnal waves along the north-west coast of Scotland has been very little known, since this is masked by the northwards waves in the real sea. In Fig. 1P, the propagation of the southwards waves can be traced clearly, although their amplitude diminished very rapidly with distance.

Case 2 is a hypothetical situation in which the direction of earth rotation is east to west without changing all other conditions. Comparing Fig. 1 and Fig. 2, we understand how much the earth rotation contributes to the pattern of the forced oscillations in this sea. A remarkable difference between Fig. 1P and Fig. 2P is the position of the amphidromic point: the former is off Germany, and the latter is near Great Yarmouth. Otherwise, the general pattern of phase lines in the two cases is quite similar.

However, the patterns of amplitude lines in the two cases are completely different. In Fig. 1A, most amplitude lines run along the long axis of the North Sea, the water level in the British side being considerably higher than the continental side. In Fig. 2A, the most amplitude lines run across the width of the sea, the water level in the continental side being higher than in the British side generally. The largest amplitude in Fig. 1A exceeds 60%, while the amplitude in Fig. 2A never exceeds 10%. The reason for this can be explained by comparing the amplitude patterns near the excitation points in the two diagrams. In Fig. 1A the waves near the excitation point deflect (due to the Coriolis force) north-eastwards, and escape towards the deep water area or open sea. In Fig. 2A, the waves near the point deflect south-westwards, and forced to follow along the Scottish coast southward.

4.3 Cases 3 and 4

In Cases 3 and 4, the excitation point is taken on Grid T22 (51.0°, 1.5° approx.; in the Strait of Dover). The waves generated on this point propagate into two seas, almost equally dividing their energy into two parts: the North Sea and the English Channel.

Fig. 3 shows Case 3 where the earth rotation is west to east. We have little observational or computed data to compare with this result, except for the author's earlier computation by another model in 1961 (Ref. 3) which agrees with this result. Two remarkable features can be seen: no amphidromic point; and the considerably larger amplitude along the continental side than the British side.

The amplitude reduces rapidly towards the northern entrance of the North Sea, it being only 0.3% near Shetland. (The author's earlier model could not detect such a small amplitude accurately).

Case 4 shown in Fig. 4 is again a hypothetical situation in which earth rotation is east to west, without changing all other conditions.

The phase diagram in Fig. 4P is very similar to Fig. 3P, as far as their equal-phase lines from 0° to 270° are concerned. After 270°, the lines in the two diagrams differ considerably: the lines in Fig. 3P are diagonal (SE-NW) in the North Sea; and the lines in Fig. 4P are parallel to the width of the sea.

The amplitude lines in the two diagrams have considerable differences. The lines in Fig. 3A run generally across the width of the North Sea. The lines in Fig. 4A run generally along the long axis of the sea, the amplitude in the British side being higher. However, the effect of the waves through the Strait of Dover is not very great along the British coast in Fig. 4A, compared with the effect on the continental side in Fig. 3A. This can be explained by the topography of the southern part of the North Sea (a V-shaped area formed by Great Yarmouth - Dover - The Hague); the opening of the V-shape faces in a NE direction.

The decay of the amplitude towards the northern entrance of the North Sea is less in Fig. 4A than in Fig. 3A, because the waves propagate towards the entrance through the shortest pass and relatively deep water in Fig. 3A (compare the phase patterns in Fig. 3P and Fig. 4P).

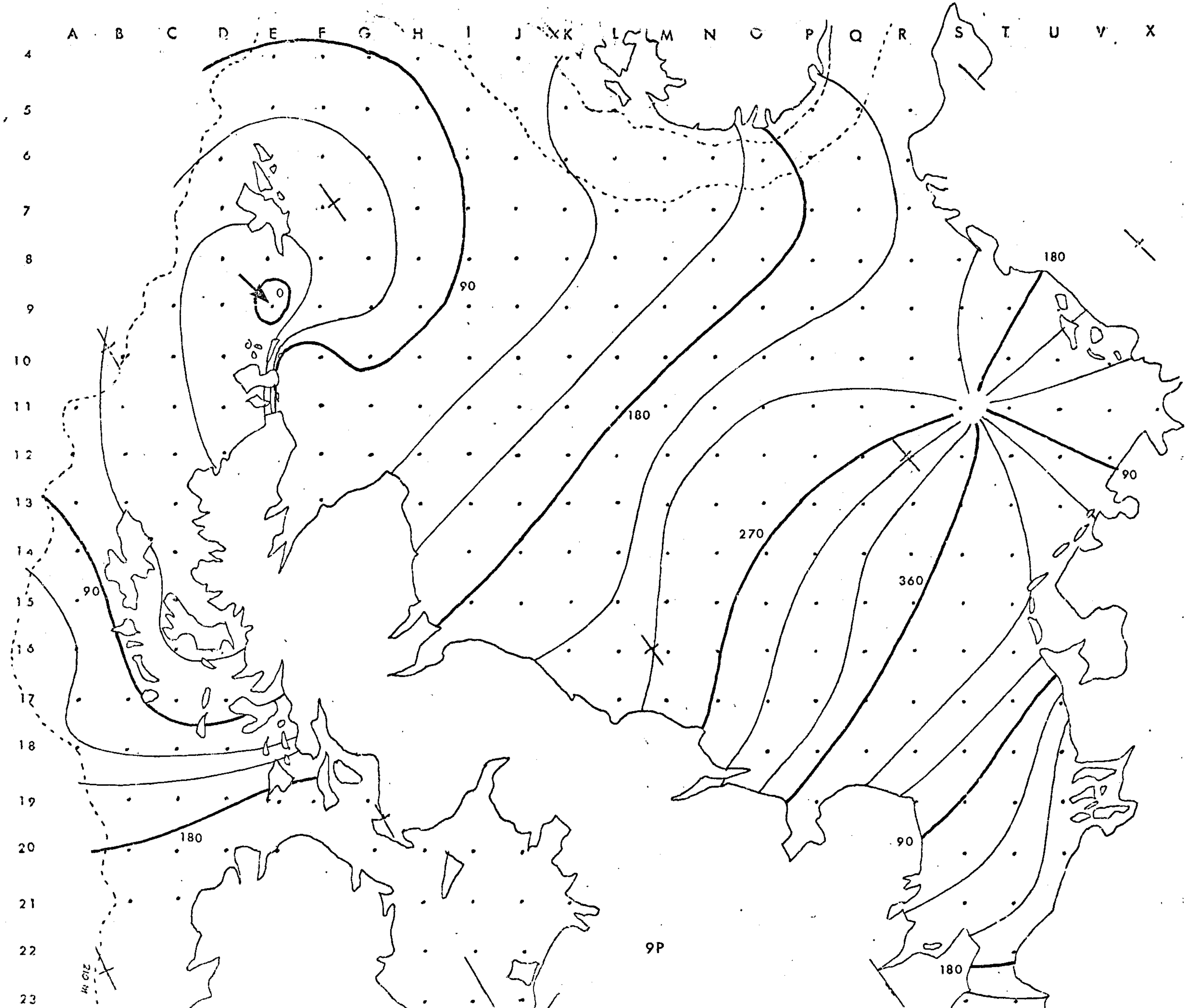


Fig. 1P Water-level response to a semi-diurnal sinusoidal excitation at a point (shown by an arrow) off the Orkney Islands. Earth rotation, from west to east. Equal-phase lines, with intervals of 30°, referred to the phase at the excitation source.

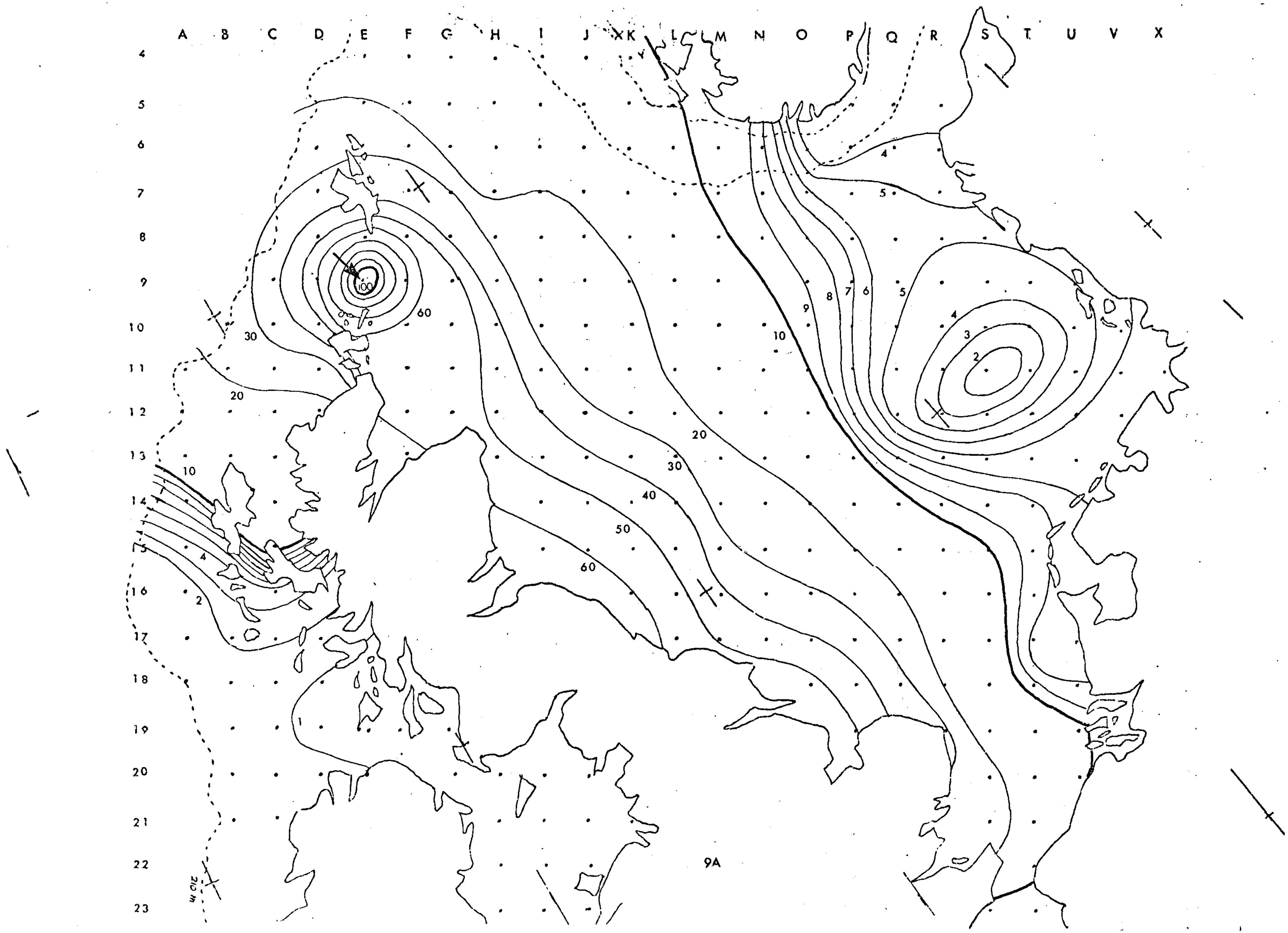


Fig. 1A Water-level response to a semi-diurnal sinusoidal excitation at a point (shown by an arrow) off the Orkney Islands. Earth rotation, from west to east. Equal-amplitude lines, with the percentages of the amplitude at the excitation source.

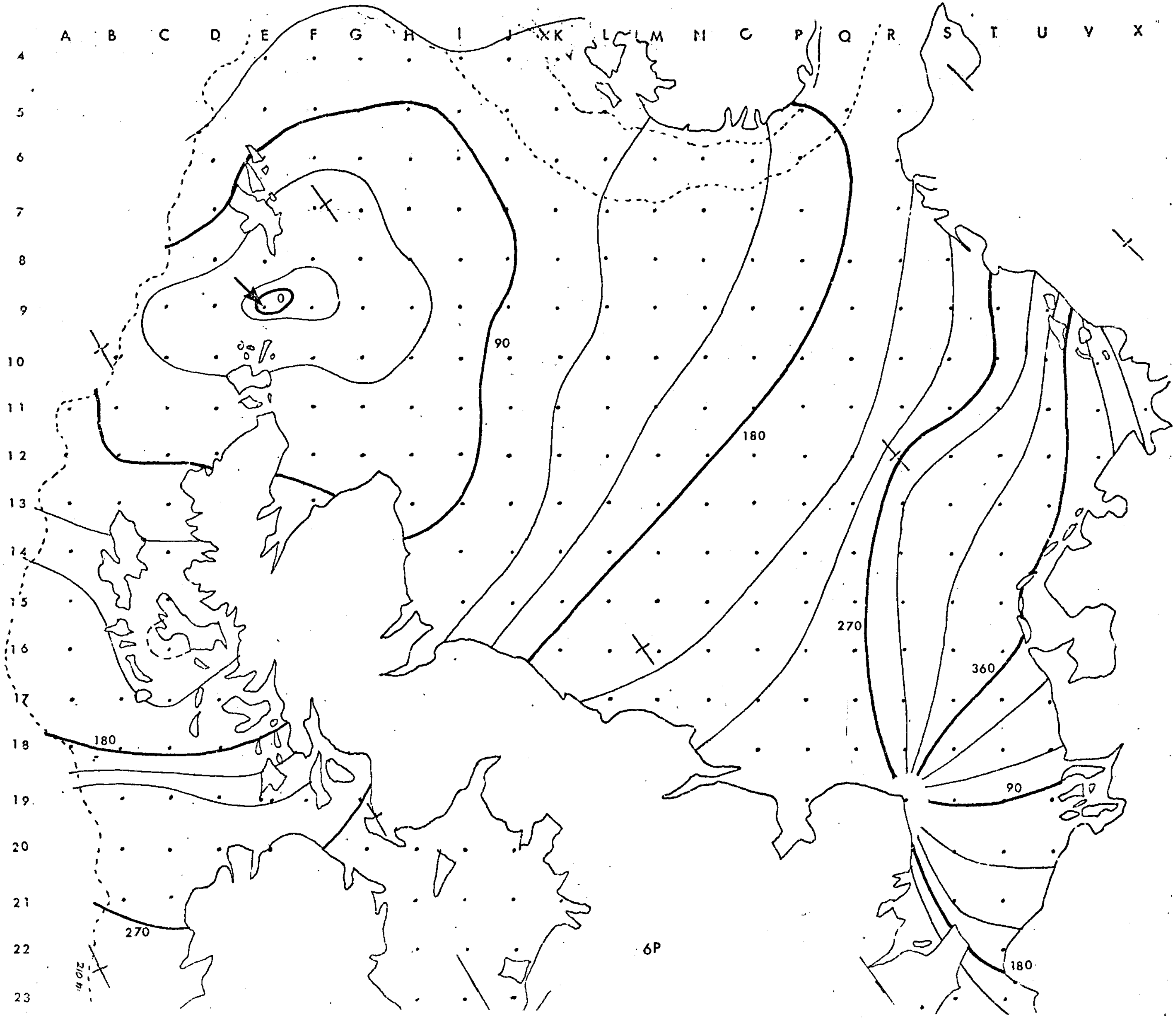


Fig. 2P Water-level response to a semi-diurnal sinusoidal excitation at a point (shown by an arrow) off the Orkney Islands. Earth rotation, from east to west. Equal-phase lines, with intervals of 30°, referred to the phase at the excitation source.

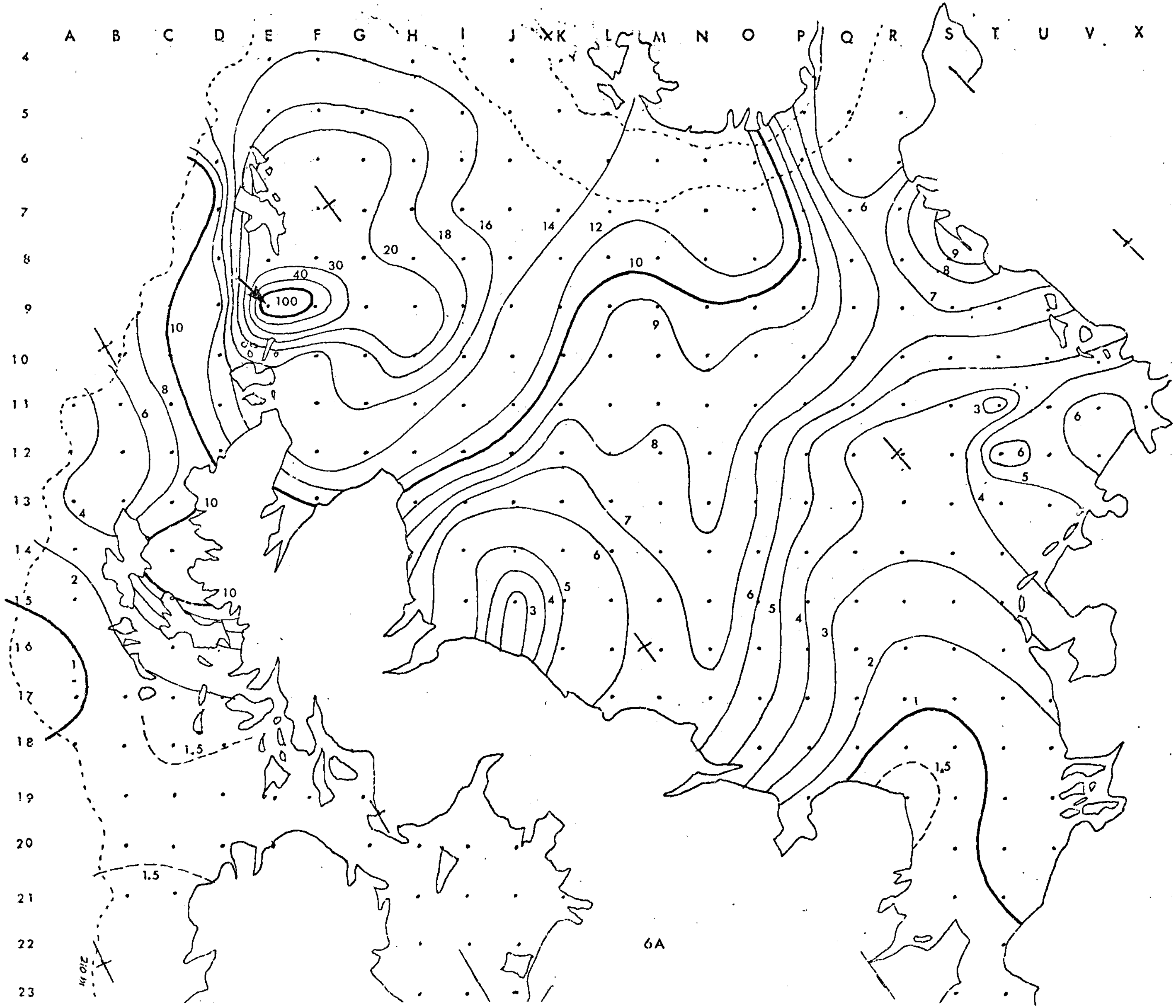


Fig. 2A Water-level response to a semi-diurnal sinusoidal excitation at a point (shown by an arrow) the off Orkney Islands. Earth rotation, from east to west. Equal-amplitude lines, with the percentages of the amplitude at the excitation source.

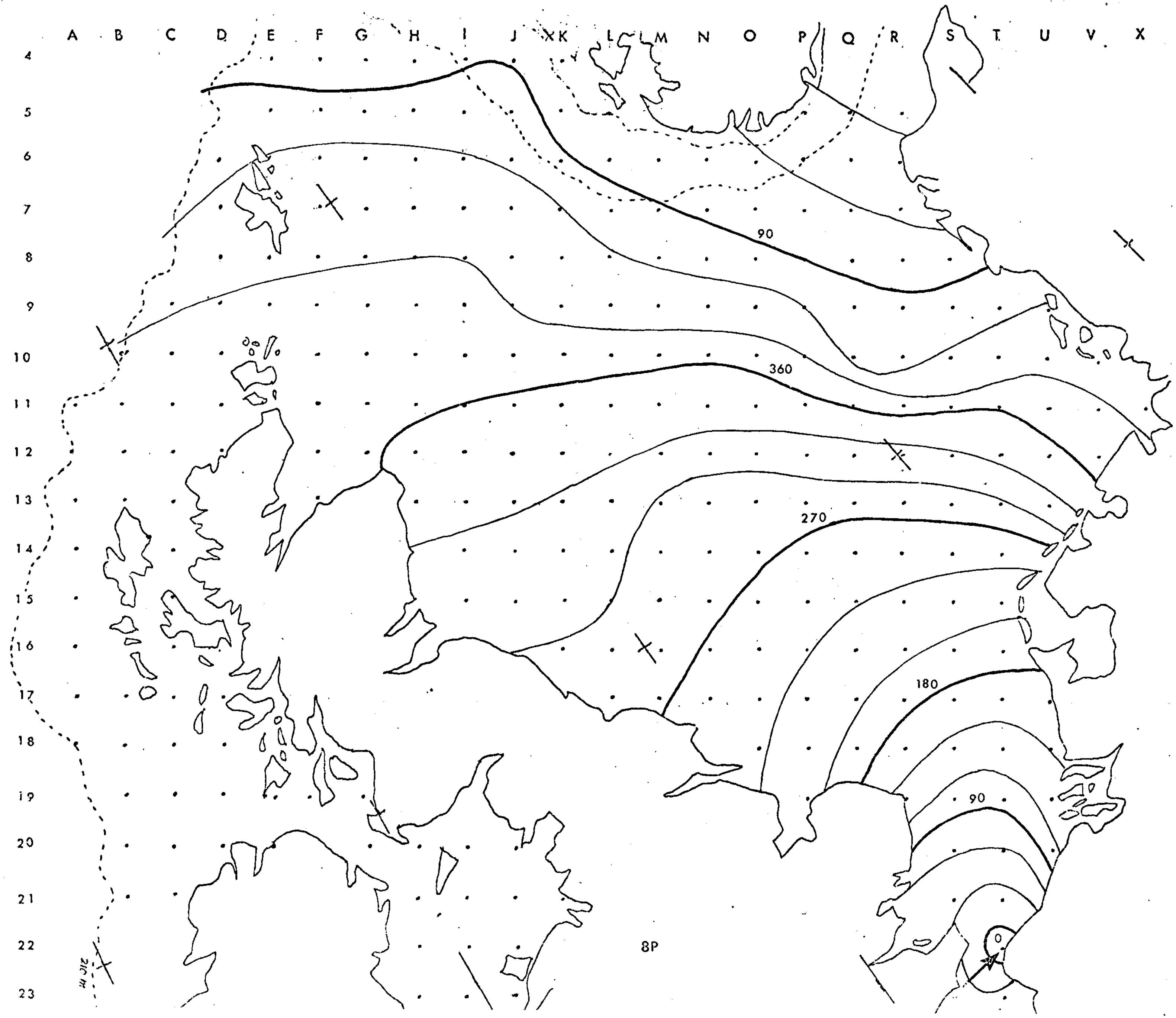


Fig. 3P Water-level response to a semi-diurnal sinusoidal excitation at a point (shown by an arrow) in the Strait of Dover. Earth rotation, from west to east. Equal-phase lines, with intervals of 30°, referred to the phase at the excitation source.

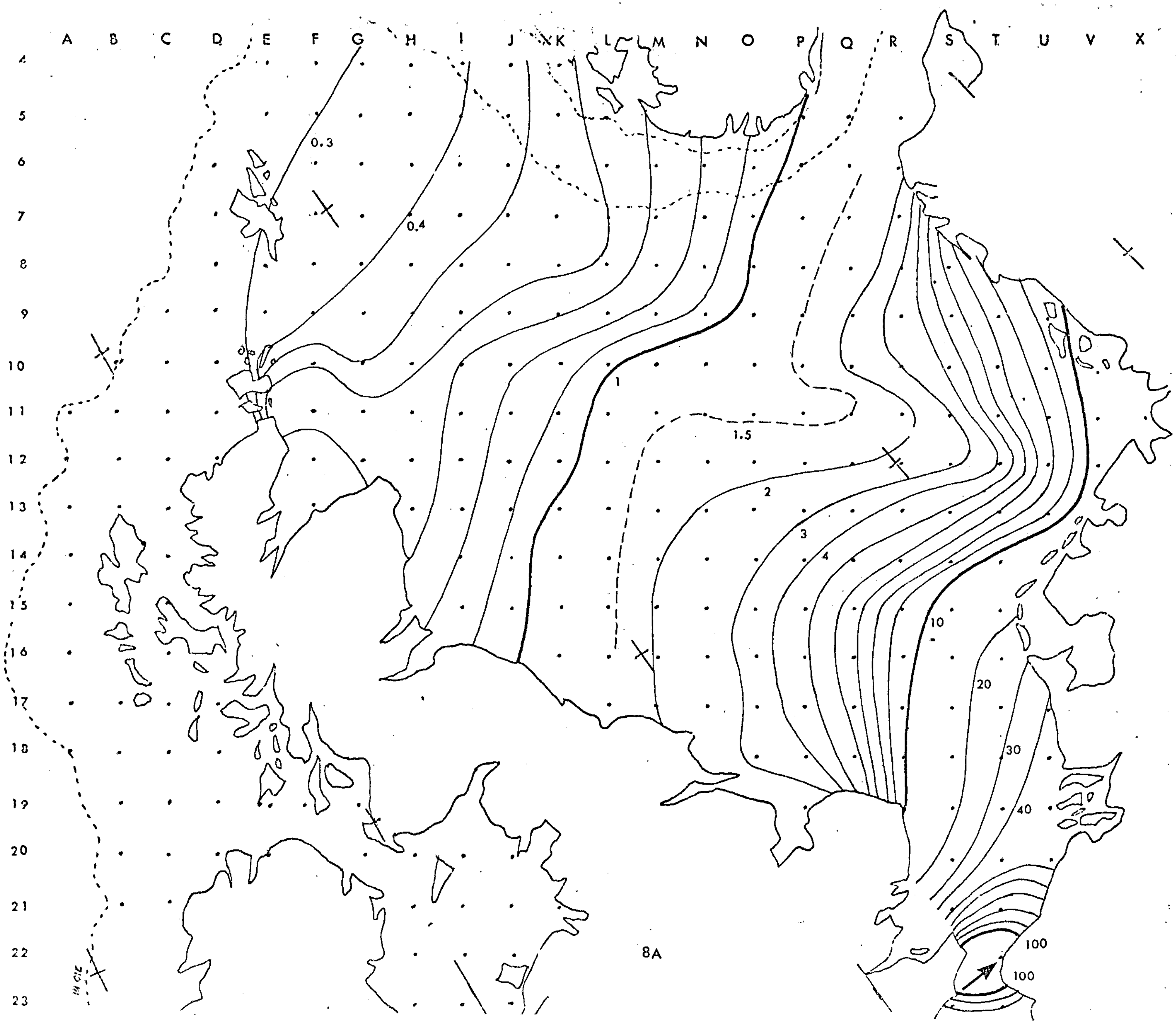


Fig. 3A Water-level response to a semi-diurnal sinusoidal excitation at a point (shown by an arrow) in the Strait of Dover. Earth rotation, from west to east. Equal-amplitude lines, the with percentages of the amplitude at the excitation source.

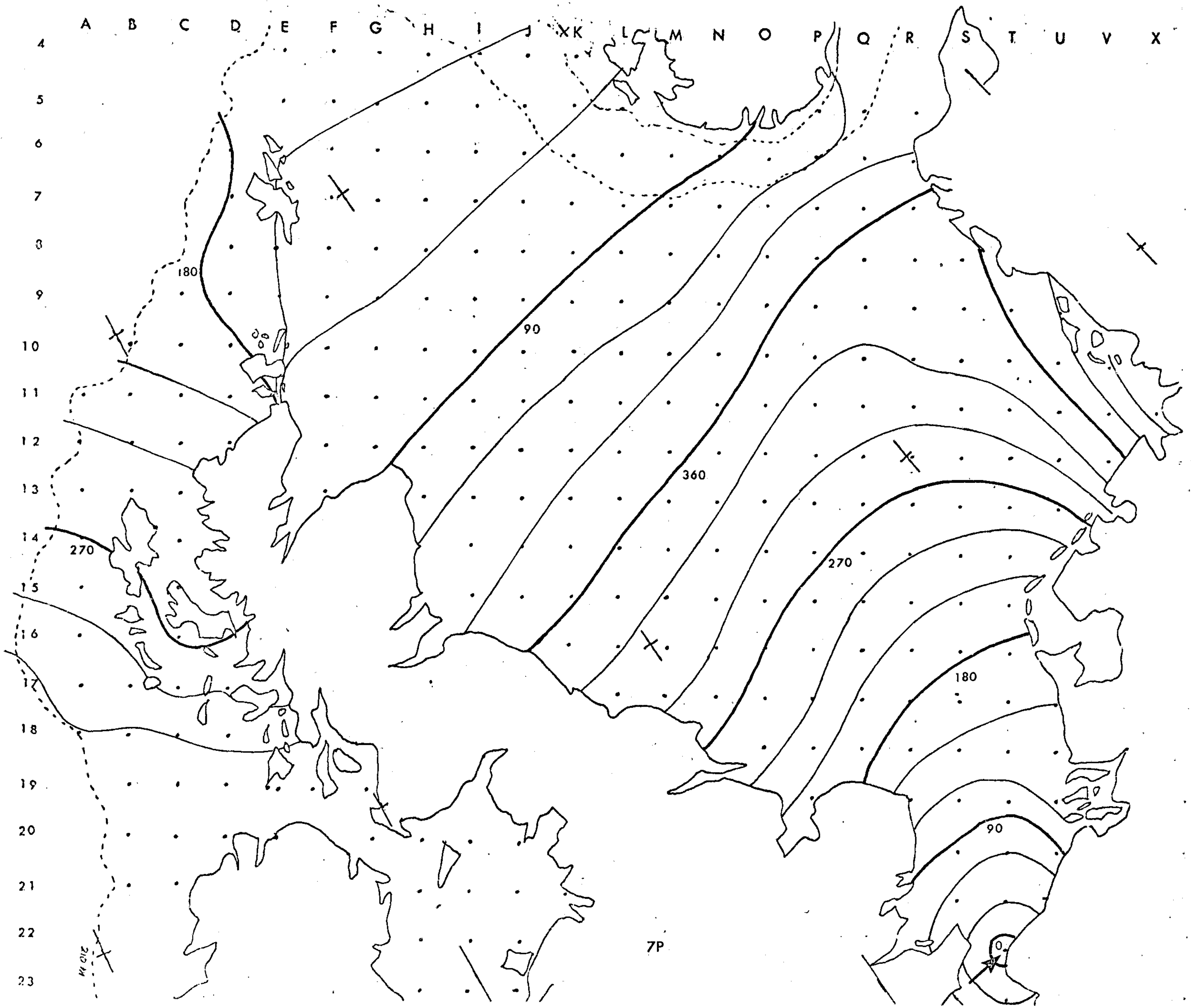


Fig. 4P Water-level response to a semi-diurnal sinusoidal excitation at a point (shown by an arrow) in the Strait of Dover. Earth rotation, from east to west. Equal-phase lines, with intervals of 30°, referred to the phase at the excitation source.

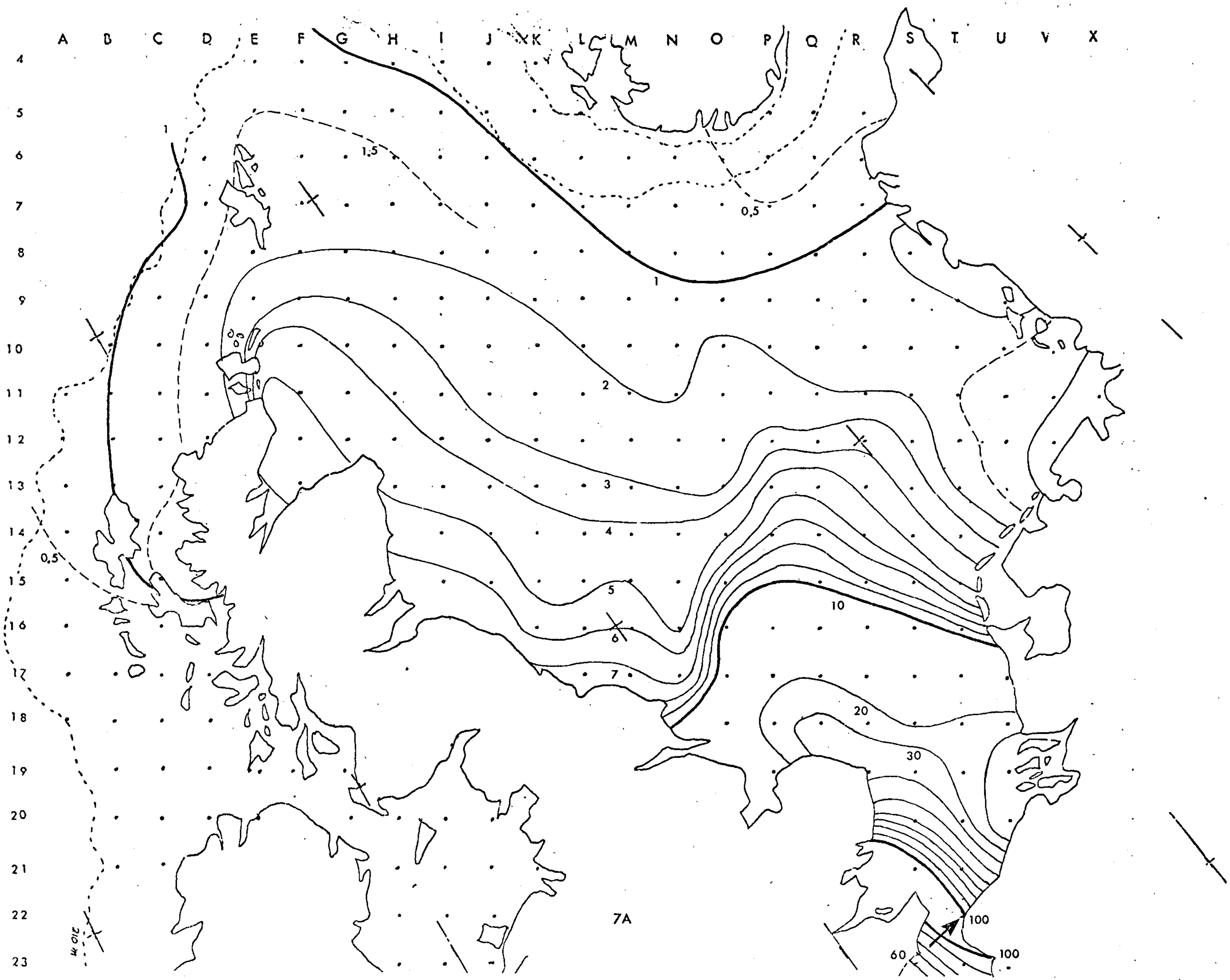


Fig. 4A Water-level response to a semi-diurnal sinusoidal excitation at a point (shown by an arrow) in the Strait of Dover. Earth rotation, from east to west. Equal-amplitude lines, the with percentages of the amplitude at the excitation source.

5. CONCLUSIONS

The interpretation of the tidal patterns in the North Sea based on the author's earlier work (1961) has been confirmed with this paper. Hypothetical cases where the earth rotation is reversed have added new information to the interpretation, while the earlier work includes a case where the rotation is set to zero.

Combining the results from the new and earlier works, the semi-diurnal tidal patterns in the North Sea can be interpreted:-

1 Without the effect of the earth rotation, the topography of the North Sea alone produces the general tidal pattern of semi-diurnal tides (the amplitude is maximum along the British coast, and minimum in the Skagerrak), but the gradient of amplitude is smaller over the whole sea area, and of course there is no amphidromic point (Appendix 3e).

2 The semi-diurnal waves through the northern entrance of the North Sea alone produce the almost natural state of the tidal pattern over the whole sea area, including the amphidromic point off Germany, but the tidal pattern in the southern part of the sea is different from the natural state. Notably the amphidromic point in this area is missing (Fig. 1).

3 The semi-diurnal waves through the southern entrance of the North Sea alone have appreciable effect on the continental coast, from the Hague to German Bight, but the same degree of effect appears along the British coast only from Dover to Great Yarmouth. These waves produce no amphidromic point (Fig. 2).

4 The amphidromic point in the southern North Sea is formed only when the semi-diurnal waves from the northern and southern entrances of the sea are merged (Appendix 3a).

5 The propagation of semi-diurnal waves from the Strait of Dover to the northern entrance of the North Sea, and towards the north-west coast of Scotland, has been made clear (Fig. 1).

6 The hypothetical case of the reversed earth rotation shows that this not only creates the reversed tidal patterns generally, but also creates a considerable difference in the range of amplitude. The great change of the position of an amphidromic point is interesting (Fig. 2 and Fig. 4).

7 If the Strait of Dover is closed, the semi-diurnal amphidromic point near the strait would disappear, but that off Germany would be enhanced (Appendix 3d), compared with the case shown in Appendix 3b.

The first aim of obtaining data in this paper was to test the new model itself including its facility for the Coriolis force, but the data is also useful for interpretation of the tidal patterns in the North Sea. Various components of tide will be simulated by the same model, and this paper would be a part of the series of work.

REFERENCES

(1) S. Ishiguro (1961):
An electronic analogue method for tides and storm surges, and some applications to the North Sea.
Proceedings of the Symposium on Mathematical-Hydrodynamical Methods of Physical Oceanography, September 1961, Hamburg, pp. 265-269.

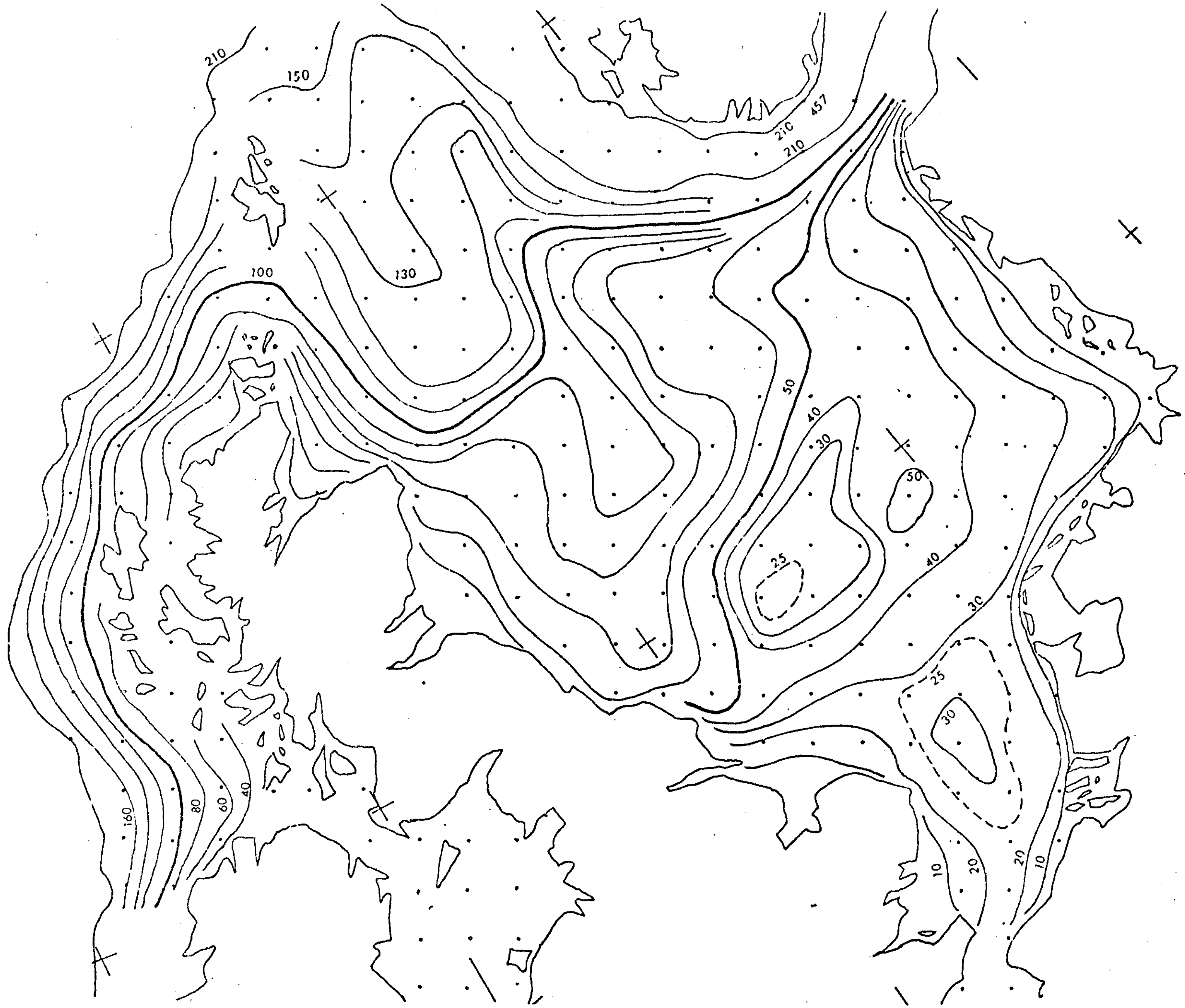
(2) S. Ishiguro (1963):
A short report on storm surges in the North Sea.
Report for the Advisory Committee on Oceanographic and Meteorological Research, October 1963, pp. 1-9.

(3) S. Ishiguro (1966):
Storm surges in the North Sea.
Report for the Advisory Committee on Oceanographic and Meteorological Research, Paper 25(iii), pp. 1-57.

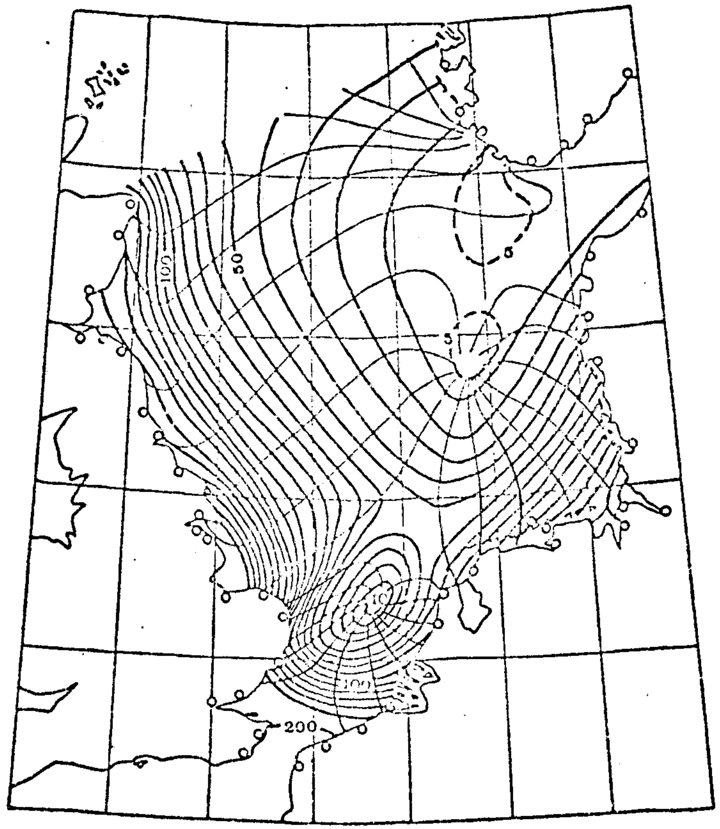
(4) S. Ishiguro (1973):
Main computation network, a part of the electronic model for tides and storm surges.
Reproduced in IOS Internal Document 89, pp. 1-46.

(5) S. Ishiguro (1980):
Arrangement of the main computation network for the sea around the British Isles.
IOS Internal Document 64, pp. 1-53.

(6) S. Ishiguro (1980):
Notes on the initial operations of the new electronic model for tides and storm surges.
IOS Internal Report 100, in preparation.

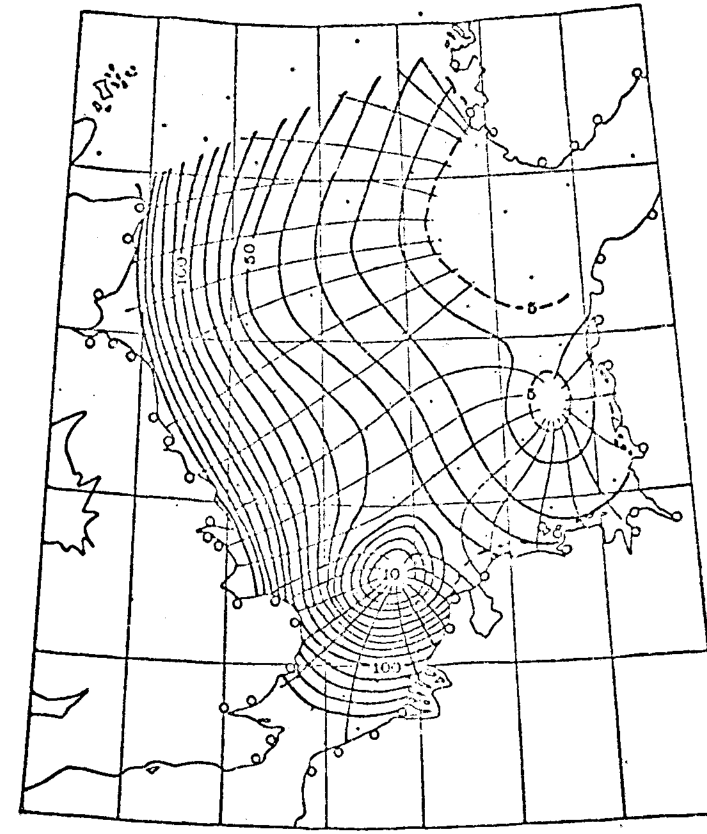


Appendix 1 Undisturbed water depth (in metres) of the North Sea, smoothed from quantized values for 50 km-square grids.



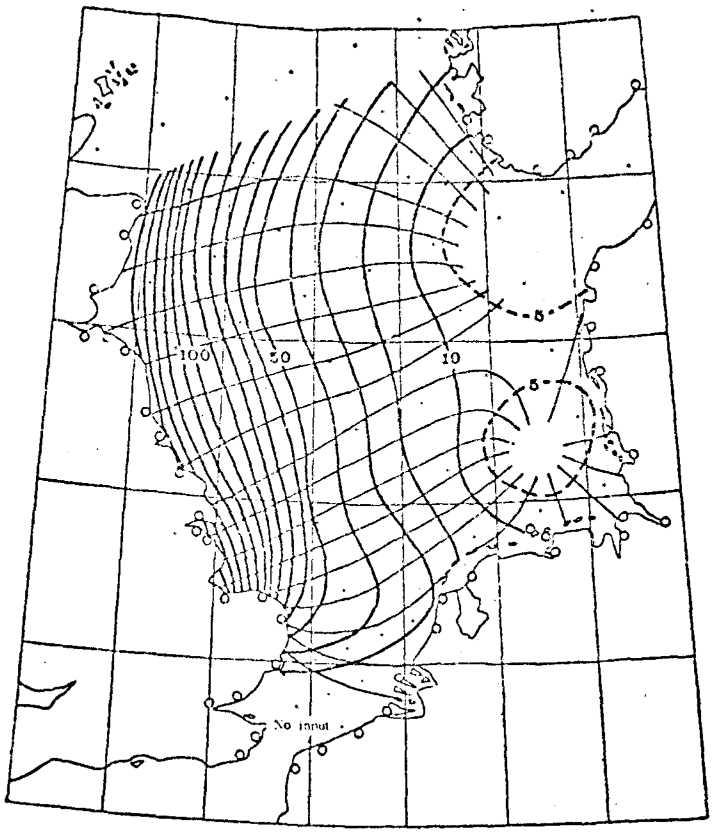
Appendix 2

Amplitude/phase diagram of the M_2 tide in the North Sea, based on observational data. (Arranged by the German Hydrographic Office, 1941).



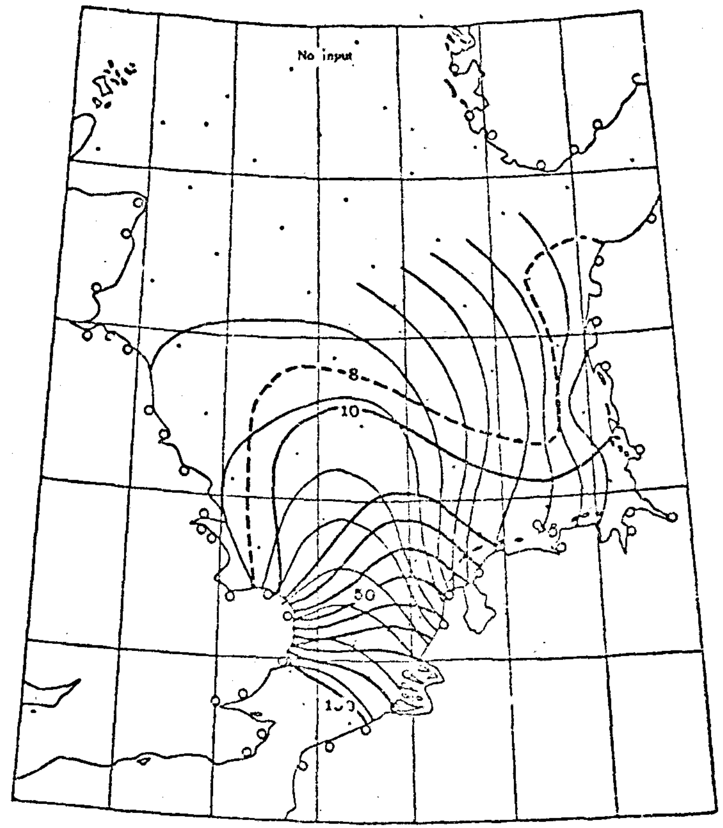
Appendix 3a

Amplitude/phase diagram of the M_2 tide in the North Sea. (Computed by S. Ishiguro, 1961).



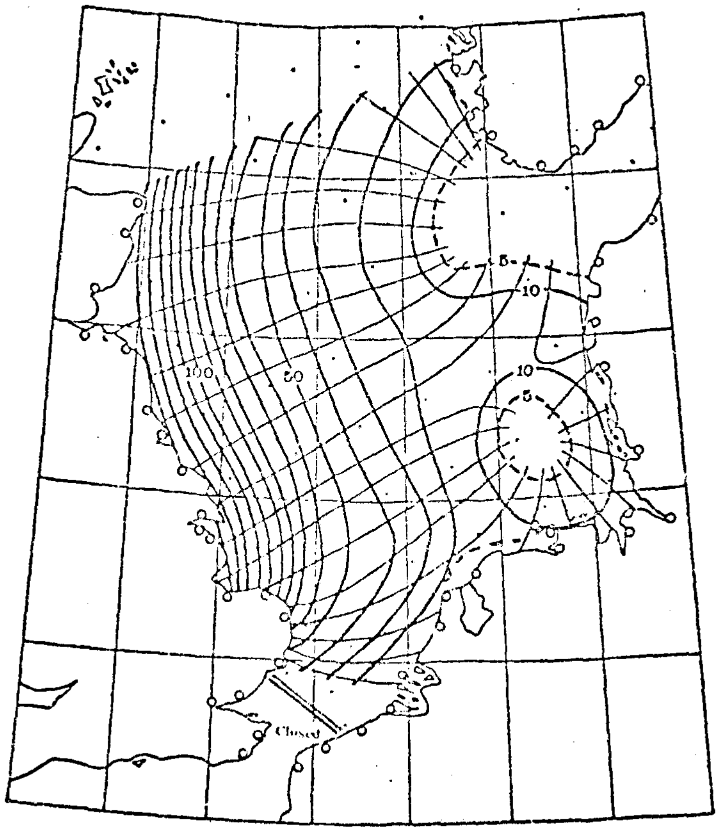
Appendix 3b

Amplitude/phase diagram of the M_2 tide in the North Sea, waves through the northern entrance of the sea alone, with the southern entrance opened. (Computed by S. Ishiguro, 1961).



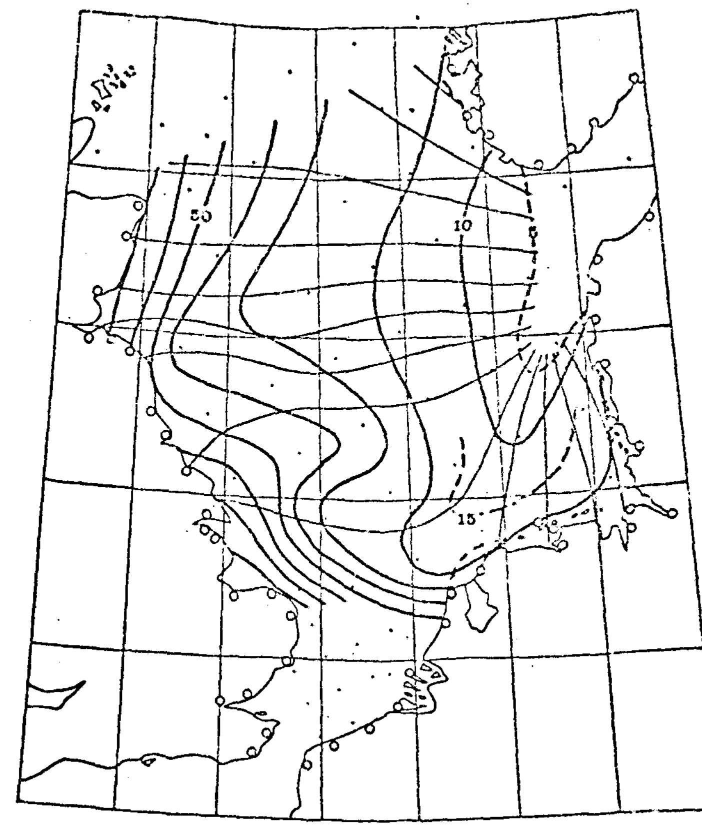
Appendix 3c

Amplitude/phase diagram of the M_2 tide in the North Sea, waves through the southern entrance of the sea alone, with the northern entrance opened. (Computed by S. Ishiguro, 1961).



Appendix 3d

Amplitude/phase diagram of the M_2 tide in the North Sea, waves through the northern entrance of the sea alone, with the southern entrance closed. (Computed by S. Ishiguro, 1961).



Appendix 3e

Amplitude/phase diagram of the M_2 tide in the North Sea, without the earth rotation. (Computed by S. Ishiguro, 1961).