Numerical calculation of wave refraction in the Adriatic Sea

by

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Abstract

In the study of coastal phenomena the most important cause of the modifications of a shoreline is the action of waves. To determine the parameters characterizing a wave field, we have used the Sverdrup-Munk-Bretschneider method, which permits the deduction of significant period and height of waves from meteorological data. The meteorological condition of 3-4-5 November 1966 has been taken for this first study because it corresponds to a peak storm surge that affected Venice very seriously. The wave data obtained were used as input for wave refraction diagrams constructed by means of computer programs. The numerical method for constructing the refraction diagrams takes out everything subjective that is implied in the by hand constructed ones and is limited in accuracy only by the known details of bottom topography.

In this preliminary report only the study of the variation in direction — and not in wave height — has been made. However, this information was sufficient to reveal the convergences in specified sections of the coastline. The results appear to be in good agreement with the actual locations where intense damages were produced by the storm surge of November 1966.

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The wave field characterizing a sea causes short term variations, such as the ones produced by the big surges of stormy weather, that dissipate their energy against the coast; and it causes also the long term modifications, such as the ones giving rise to erosion or accretion in the various parts of a coastline. These preliminary results are the first part of a general research program about the evolution of the coast surrounding the lagoon of Venice and the causes that produce this evolution. The beginning point in this program has been the study of the wave field of the Adriatic sea. For this, two lines of approach can be followed. The first one is possible if wave records, taken from several points in the sea, are available. The second line of approach derives the characteristics of the wave field from meteorological data. From this second point of view, the method developed by SVERDUP and MUNK, and revised by BRETSCHNEIDER, has been used. The method is based on the concept of significant wave, introduced by Munk, and to have a critic judgement about its validity, it has been tested with direct analysis of some wave records taken on the E.N.I. platform situated in the Southern part of the Adriatic sea, far offshore from Pescara, on a depth of about 120 m, during the period February-March 1970. Direct Fourier analysis was applied to the wave records and the results obtained, for the interested days, were in good agreement with the data deduced by means of the S.M.B. method.

The Adriatic sea is a basin characterized, in its Northern part, by a very regular bottom topography, with a slope much less than 1 : 1000. Both diffraction and reflection, therefore, are completely insignificant for the propagation of waves shoreward. Moreover, the step in the central Adriatic is also negligible in respect to reflection; both for the slope that would give a reflection coefficient never overcoming

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the 10 %, and more essentially because the step is in the wave generating area. Therefore the essential factor governing the variation of wave path in the Adriatic is refraction. Of course, just near the coast or the coastal structures, diffraction and other phenomena become important. These effects have not been treated in this preliminary work.

In this study, only the modifications in direction (and not in height) of the wind generated waves in their path shoreward have been considered. As input the wave data were used as deduced applying the S.M.B. method from the meteorological conditions of the storm of the 3-4-5 November 1966 [Fea, 1966]. The following table shows the significant data resulting from this analysis :

Time of the synoptic map G.M.T.	Significant period	Significant height	Wind direction in respect to the North.
3 November 1966 12 hours	6 sec.	5.6. feet	160°
3 November 18 hours	8 sec.	11.2 feet	160°
4 November 00 hours	10 sec.	16.5 feet	150°
4 November 06 hours	10.9 sec.	20.5 feet	140°
4 November 09 hours	12 sec.	22.5 feet	140°

At 09 GMT Nov. 4 the situation reached its climax, then the wave field decayed.

It is known that the wind generated waves have not strictly the same direction of the wind, but they spread around it, and that in an angle of about 30° to each side of the wind direction, the waves lose at the most 20 % of their energy in respect to the central following the wind direction. So, for every wave period, different directions other than the central must be considered.

The two periods of 8 sec and 12 sec have been chosen as characterizing the wave field developed during the storm of 3-4-5 November 1966. For each period of 8 and 12 sec three directions have been considered : 85° - 95° - 105° relative to the particular Cartesian system chosen on the chart of the Adriatic sea in scale 1 : 750.000, as reported in fig. 1-3-5-9-11.

With respect to this system of coordinates, the mean directions of wind are 85° and 105°, in the two considered cases of 8 sec and 12 sec respectively.

To have the refraction of wave fronts, one has computed the variations in direction of the orthogonals to wave fronts, that represent something like « wave rays », that is « paths of wave energy ». Their convergence towards or divergence from particular points give an evaluation of how the wave energy is concentrated or scattered on the various parts of a coast. This is of course directly correlated with the destructive effects that the dissipation of wave energy has on the coastal structures.

To get the refraction diagrams, a numerical method has been used, which is limited in accuracy only by the known details of the bottom topography. On the basis of simple considerations, a computer program has been written, by means of which one computes step by step, the variations in wave directions, starting from the fetch front in deep or shallow water, and going shoreward, arriving just at the coastal line. The program is based on the transformation of the field of depths into a celerity field.

It starts from a general chart of the Adriatic sea in scale 1 : 750.000 in which one can see the general pattern of wave refraction all over the whole sea. To have more details one passes then to a chart in scale of 1 : 250.000 in which the variations in sea topography, much more specified, allow a better description of wave refraction. In this passage, being the scale reduced of 1/3 in respect to the first one, the number of rays has been increased in consequence; the rays marked with a cross in fig. 2-4-6-8-10-12 are the ones directly consecuting from the first chart, and the others are interpolated between each couple of the « ancient » rays for what concerns their starting points and angles of incidence.

Figures from 1 to 12 represent the general situation in the Adriatic for the periods of 8 sec firts and 12 sec after, successively for the three overmentioned directions of incidence. For each general pattern there is, on the right, the corresponding particular one in the northern part of the Adriatic. On the charts, the numbers distinguish the various parts of the littoral as it follows :

(1) = the Po Delta
(2) = littoral under the Chioggia inlet
(3) = the Chioggia inlet
(4) = the littoral of Pellestrina
(5) = the Malamocco inlet
(6) = the littoral of Lido beach
(7) = the inlet of Lido
(8) = the littoral of Jesolo

From what can be seen from the various diagrams, one can characterize the south-east wave field (that is the wave field induced by south-east wind) along the coast of the lagoon of Venice with the following points :

1. Divergence from the Pô Delta (1) to the inlet of Chioggia (3).
2. Very big convergence on the littoral of Pellestrina (4).
3. Among the inlets of the lagoon, the biggest convergence is on the inlet of Lido (7).
4. Convergences on two points on the littoral of Jesolo (8).

Moreover, there must be noted the great divergence that spreads out the two adjacent rays that arrive at coast at the opposite sides of the Pô Delta (1). The points 1.-2.-3.-4. are in quite good agreement with the effects of the storm of 4 November 1966. Infact, the littoral of Pellestrina (4) was the most damaged, the inlet of Lido (7) was completely destroyed in its terminal jetties, the littoral of Jesolo (8) was also damaged, while the littoral (2) just south the inlet of Chioggia (3) suffered the less from the storm.

These are of course only preliminary results. Many points must be specified in great detail and many steps must be made to arrive from these qualitative results to quantitative ones, that permit to say in which manner the various parts of the coastline are affected by the Adriatic wave field.

References

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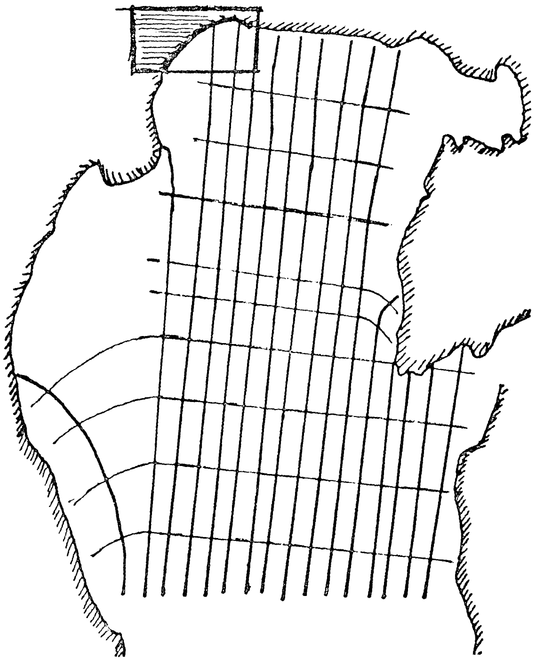

FIG. 1. — T = 8 sec. α = 85°

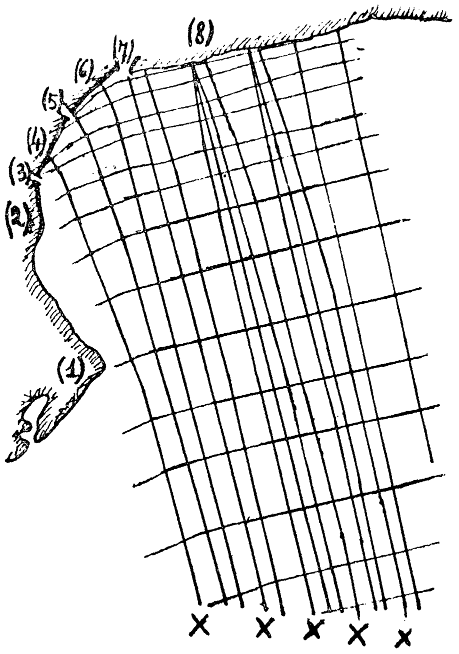

FIG. 2. — T = 8 sec. α 85°

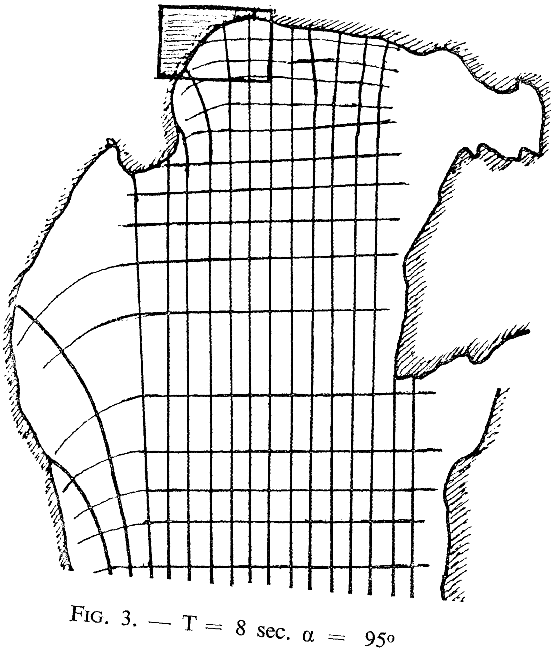

FIG. 3. — T = 8 sec. α = 95°

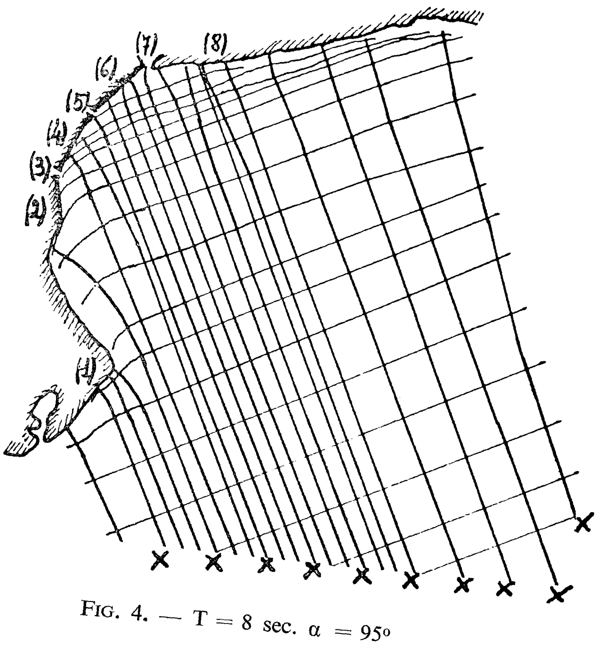

FIG. 4. — T = 8 sec. α = 95°

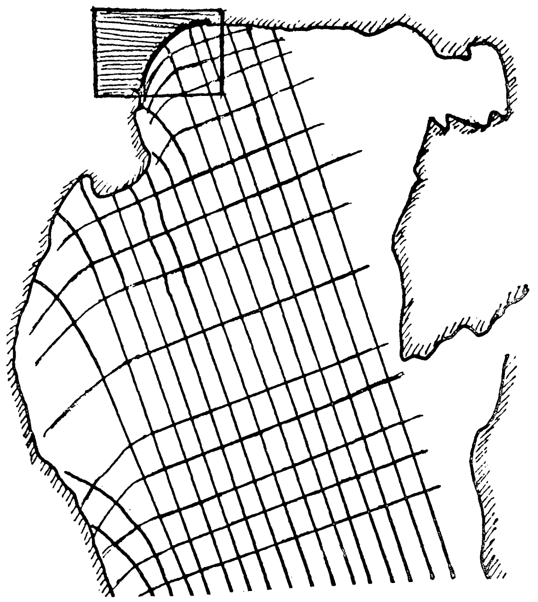

FIG. 5. — T = 8 sec. α = 105°

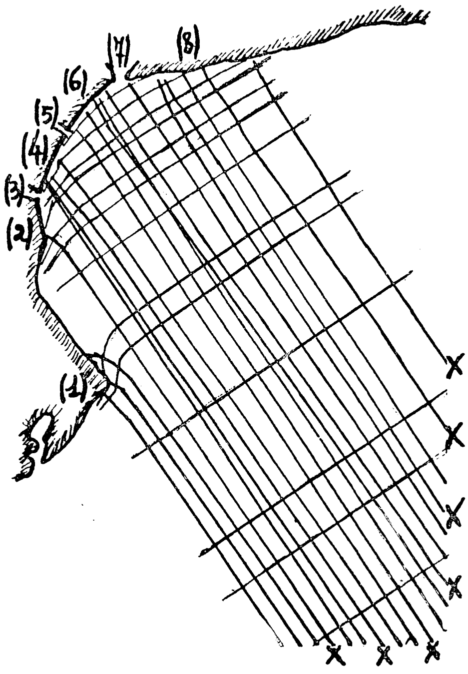

FIG. 6. — T = 18 sec. α = 105°

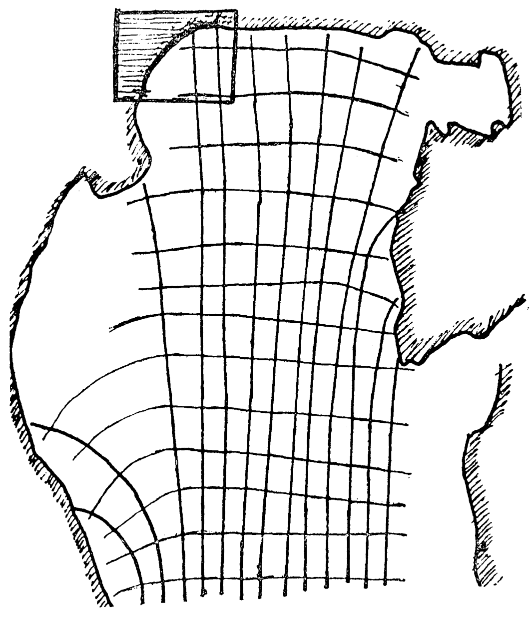

FIG. 7. — T = 12 sec. α = 85°

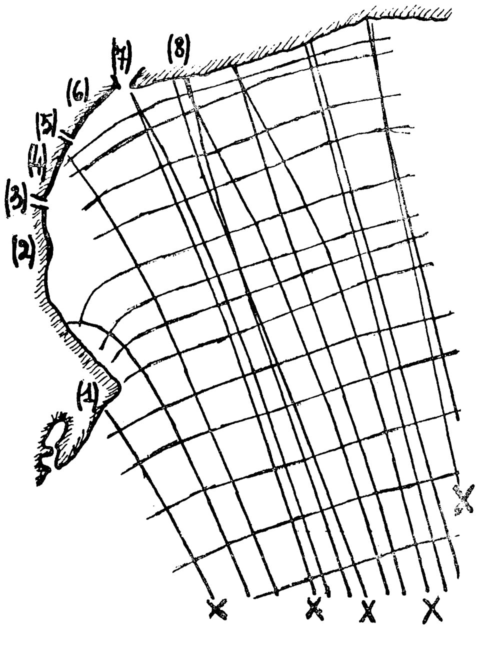

FIG. 8. — T = 12 sec. α = 85°

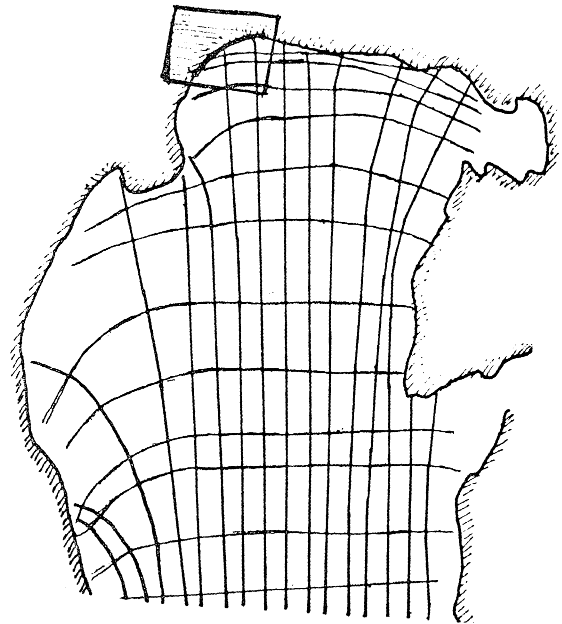

FIG. 9. — $T = 12$ sec. $\alpha = 95^\circ$

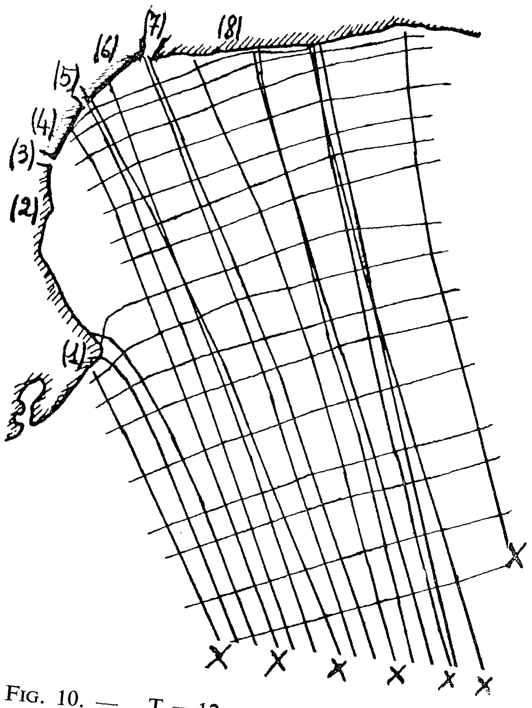

FIG. 10. — $T = 12$ sec. $\alpha = 95^\circ$

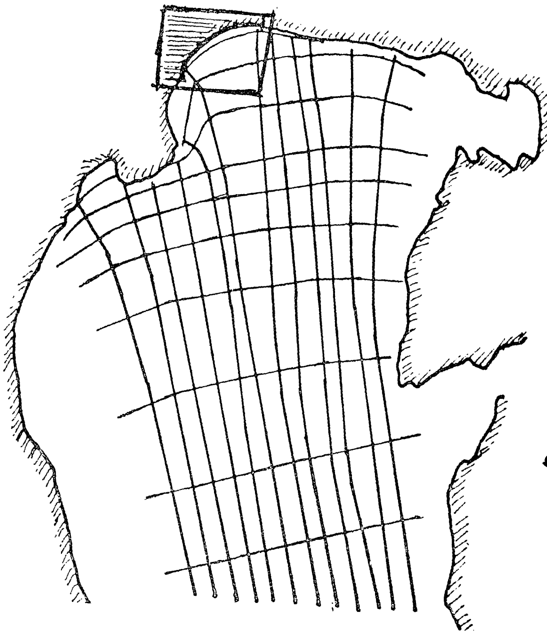

FIG.11.

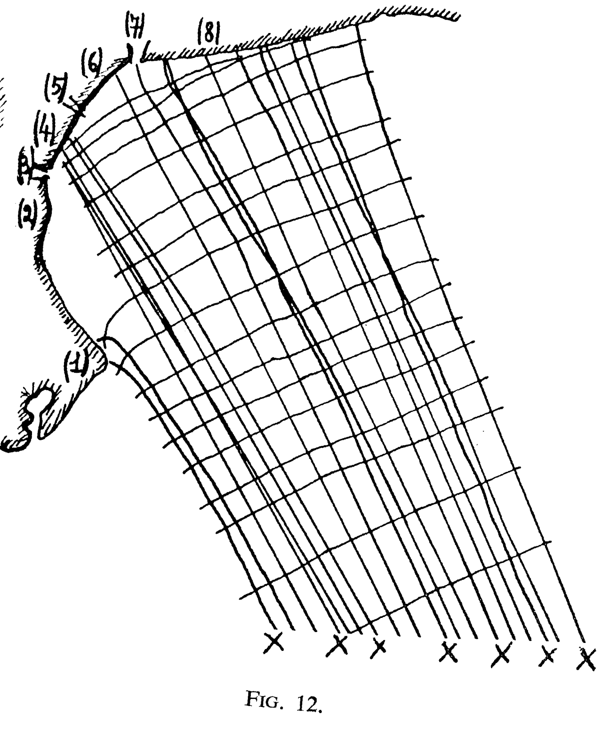

FIG. 12.