CHAPTER 42

COMPARISON BETWEEN THE RESULTS OF LITTORAL-DRIFT COMPUTATIONS AND CUBATURE OF DEPOSITS IN A DREDGED CHANNEL

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ABSTRACT

The total annual volume of littoral drift on either side of the mouth of Sergipe estuary, in the Northeast of Brazil, has been determined by applying Caldwell's, Castanho's and Bijker's methods to the wave characteristics that had been recorded at a twenty-metre depth of water, over a whole year, for the design of an offshore oil terminal.

The three computation methods yielded the same order of magnitude which was found to amount to about 800000m^3/year. The dominant drift is southwestward, and its predicted amount is 660000m^3/year. It was also found that although the three methods lead to total results of the same order of magnitude, they do not agree as to the variation of littoral drift over the year for the same waves.

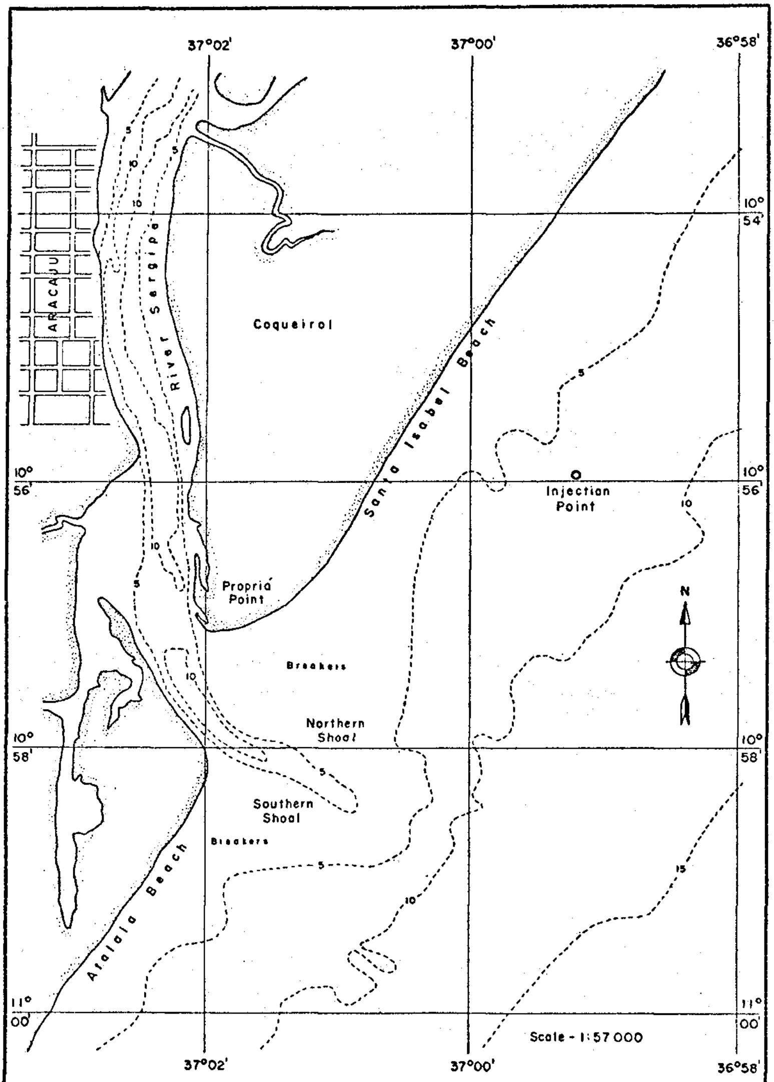
An eight-metre deep shipping channel has been dredged accross the bar. The channel was surveyed in December 1971, August and December 1972, and a cubature of the deposits was made after the littoral-drift computations had been carried out. As the latter had been performed on a monthly basis, a comparison became possible between predicted and actual volumes of deposits for the same lengths of time.

The predicted volumes for the whole year were found to be from 34 to 46% greater than the actual results. However, for the time interval August-December 1972 a remarkable agreement was found between predicted and actual results.

I) STATEMENT OF THE PROBLEM

Aracaju harbour, sited at the capital of the State of Sergipe, in the Northeast of Brazil, lies inside an estuary with small upland flow. Although the estuary offers stable depths of 8 to 10m and widths from 600 to 1000m, its entrance is restricted by a bar over which the control depth has remained at a value of 3.5 ± 0.5m over the last fifty years. Fig. 1 is a key map of the area under consideration.

Long, fairly straight, flat sand beaches stretch out to both sides of the estuary entrance, on a Southwest to Northeast alignement. The mean beach slope is 1/276 from the 0m to the -5m contour. Littoral drift occurs on both shoreline directions. The littoral-drift materi



KEY MAP (ARACAJU BAR, STATE OF SERGIPE, BRAZIL)

FIG. 1

al is fine sand with a mean diameter of 0.11mm. The bed material in the outer stretches of the estuary is the same fine sand from the continental shelf. The mean spring tidal range at the estuary entrance is about 2m.

A radioactive-tracer experiment carried out from January to June 1971 by INSTITUTO DE PESQUISAS RADIOATIVAS (IPR-Nuclear Research Institute, Belo Horizonte) with the assistance of INSTITUTO DE PESQUISAS HIDRÁULICAS DA UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL (Hydraulics Research Institute of the Federal University of Rio Grande do Sul) on behalf of DEPARTAMENTO NACIONAL DE PORTOS E VIAS NAVEGÁVEIS (DNPVN - the Brazilian Federal Dock and Harbour Authority) showed the along shore drift of sand to be negligible seawards of the breaker zone. Since the sediment transport brought down by the upland flow to the estuary mouth is also negligible, littoral drift was shown to be the natural mechanism that brings about bar formation off the estuary entrance.

A few years earlier wave characteristics had been recorded over a whole year at a 20m depth of water, a few kilometres to the south of the estuary entrance, for the design of an offshore oil terminal. The waves were recorded by an inverted echosounder ("Houlographe Neyrpic") from September 1965 to September 1966. Two 12 minute long wave records were taken daily, at 09.00 and 17.00 hours. At the time of each record the wave directions were visually observed at a known depth of water from a tower on the shore.

When the results of the radioactive-tracer experiment were analysed the senior author suggested that the junior author - then a graduate student of Coastal Engineering at the Applied-Hydrology Centre in Porto Alegre but already a member of the IPR staff - should undertake an academic exercise computing the annual volume of littoral drift on either side of the Sergipe estuary entrance. The computations would be made by applying Caldwell's, Castanho's and Bikjer's methods to the wave characteristics that had been recorded for the design of the oil terminal. The aim of the exercise [1] was to compare the figures provided by the three methods.

However, DNPVN decided to dredge an eight-metre deep approach channel accross the bar shortly after the radioactive-tracer experiment reached completion. This channel was surveyed in December 1971, August and December 1972. When the littoral-drift computations had already been carried out, a cubature of the deposits in the dredged channel was made. As the littoral-drift computations had been carried out on a monthly basis, a comparison became possible between the computed results and the volumes of deposits in the dredged channel for corresponding lengths of time.

II) AN OUTLINE OF THE WAVE CLIMATE OFF ARACAJU

The wave records have been analysed according to the Tucker-Draper method. The mean periods (upward zero crossings) vary from 5 to 10 seconds. Fig. 2 shows the statistical distribution of the mean periods for the whole year. The most frequent (58.2%) mean period is 6 seconds.

The statistical distribution of significant wave heights for the whole year can be seen in Fig. 3. Significant wave heights at a 20m depth of water range from 0.6 to 2.5m, 1.1m being the most frequent value (16.6%). The significant and maximum wave height exceedance curves are shown in Fig. 4. Fig. 5 is the exceedance curve of deep-water significant wave steepness (significant wave height associated with the mean period in the same record).

Fig. 6 shows the distribution of wave directions at a 5m depth of water regardless of periods and wave heights. The most frequent (23.6%) angle of wave attack is 5° to the north of the normal to the shoreline. Most of the waves at the 5m depth (70.8%) come from the north of the latter.

The above information refers to the year as a whole. However, the wave climate off Sergipe undergoes some interesting seasonal changes. As far as periods are concerned the changes are small but it was ascertained that from September to March over 70% of the waves have periods of 5-6s. From April to August slightly longer waves occur with mean periods of 7-10s.

The seasonal variation in wave heights is more marked. Higher waves occur from April to October than from November to March. The most frequent (8.7%) maximum wave height throughout the year is 1.8m, at a 20m depth. The sum of the monthly percentages of wave heights above 1.8m varies between 25.6% and 38.6% from November to March and between 38.6% and 90.0% from April to October.

The most marked seasonal variation is the one associated with angles of wave attack at a given depth. From November to March the waves come from the north of the normal to the shoreline during practically all the time. From April to October the waves come from both quadrants, predominantly from the south in September.

In short, the summer waves are not so high as the winter waves the mean periods are about the same but in the summer the angles of wave attack are greater than in the winter and more steadily to the other side of the normal to the shoreline. In the summer they range from 15° to 20°. In the winter they amount to about 7°.

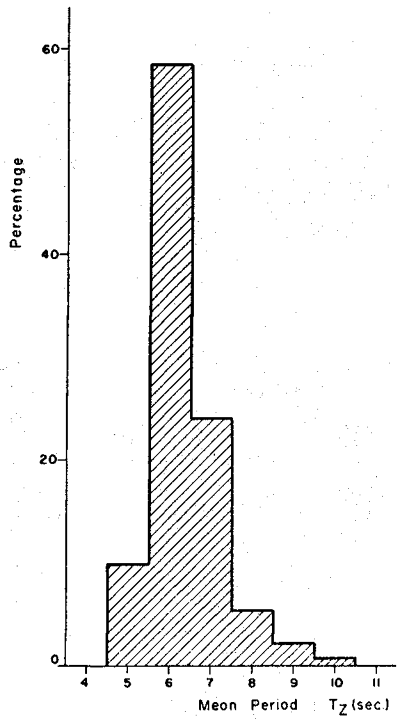
III) MAIN FEATURES OF THE COMPUTATIONS

This paper will not delve into the details of the three methods used to compute the annual volumes of littoral drift. The reader is referred to the publications in which they were proposed. Only some relevant features will be pointed out here.

The littoral-drift computations were carried out on a monthly basis. For each month the total number of seconds in the month was divided by the number of wave records that had actually been taken in the particular month under consideration. Each record was represented by a monochromatic wave of which the period was the mean period of the record, and the direction was the wave direction that had been visually observed when the record was made. The transport capacity of this monochromatic wave in cubic metres per second was calculated for each record by each of the three methods in hand. The same wave was supposed to act during the length of time corresponding to the quotient of the number of seconds in the month by the number of records actually taken. So far, evaluations of littoral-drift annual volumes have usually been made by assuming that one monochromatic wave acts all the time during the whole year.

When using Castanho's method all the waves were supposed to break as solitary waves and spilling breakers. The beach roughness

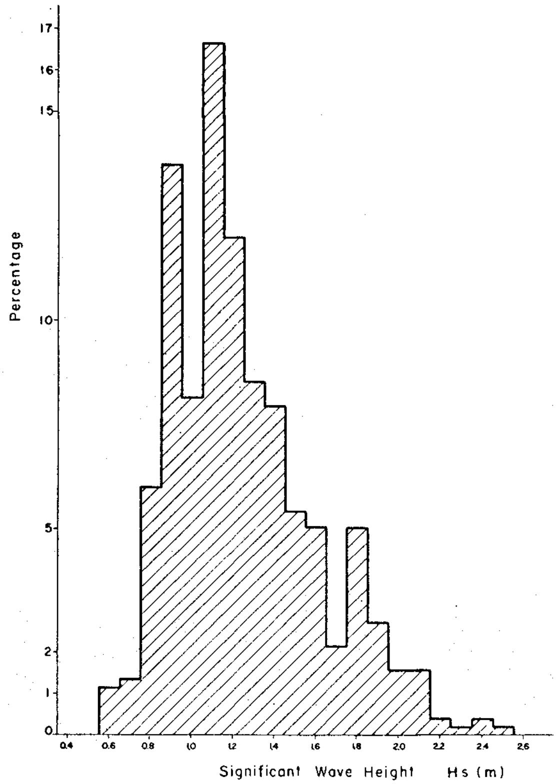
T_{med}	5	6	7	8	9	10
%	9.87	58.22	23.98	5.03	2.13	0.77



ANNUAL DISTRIBUTION OF THE MEAN PERIODS

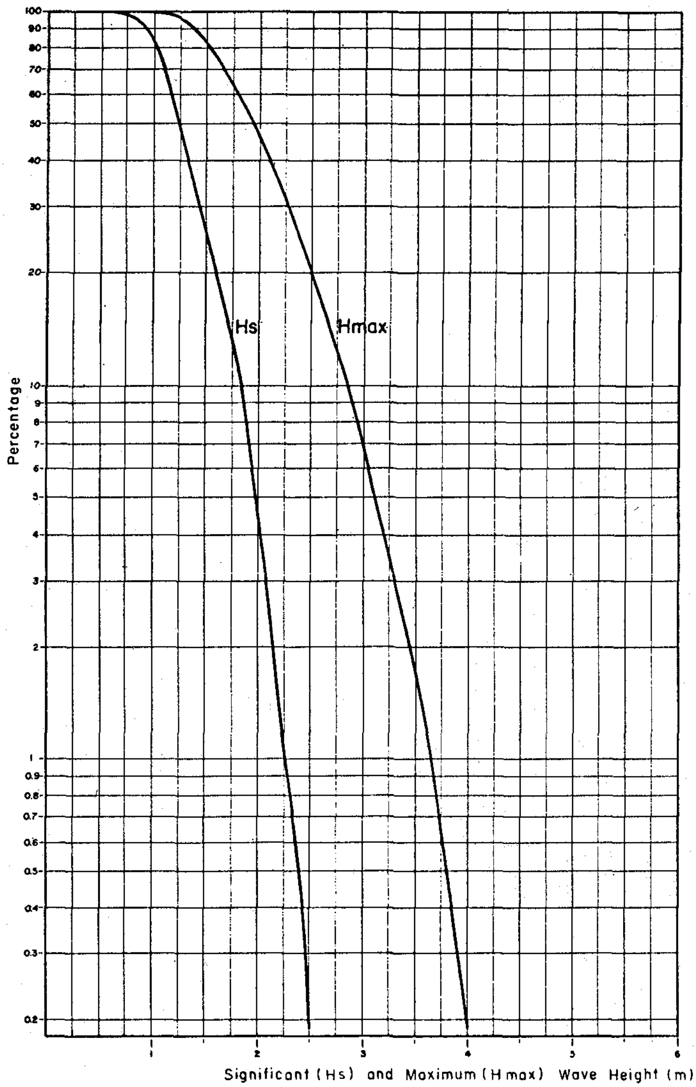
FIG. 2

Hs	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5
%	1.16	1.35	6.00	13.73	6.12	16.63	11.99	8.51	7.93	5.42	5.03	2.13	5.03	2.71	1.55	1.55	0.39	0.19	0.39	0.19



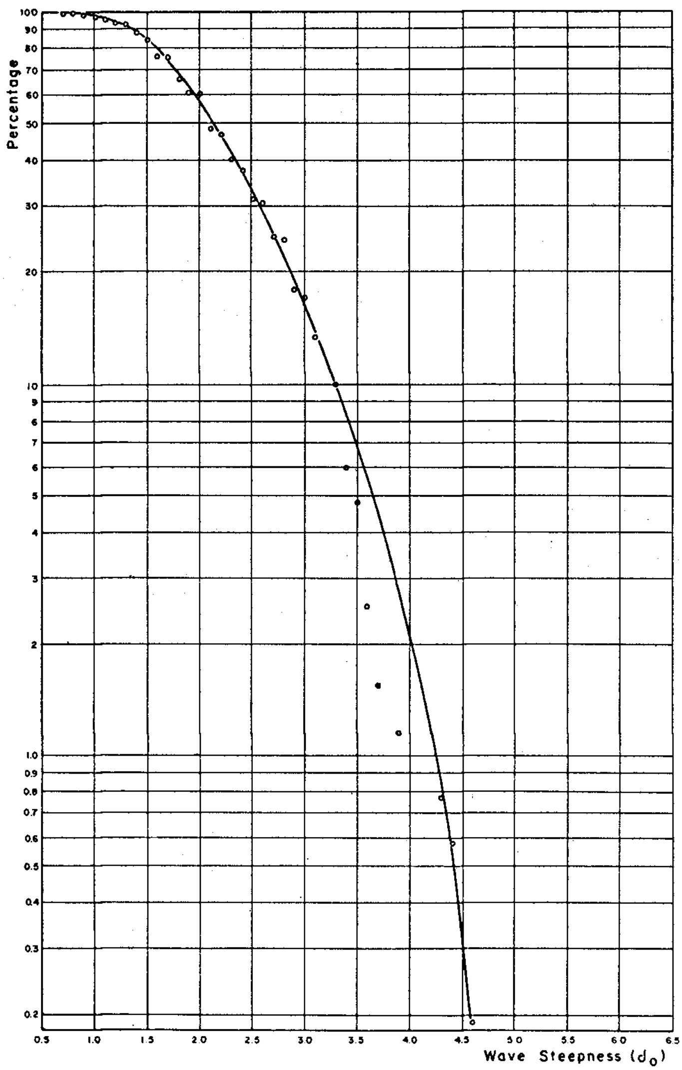
ANNUAL DISTRIBUTION OF THE SIGNIFICANT WAVE HEIGHTS AT A 20 m DEPTH OF WATER

FIG. 3



SIGNIFICANT AND MAXIMUM WAVE HEIGHT
EXCEEDANCE CURVES

FIG. 4



EXCEEDANCE CURVE OF DEEP-WATER SIGNIFICANT WAVE STEEPNESS

FIG. 5

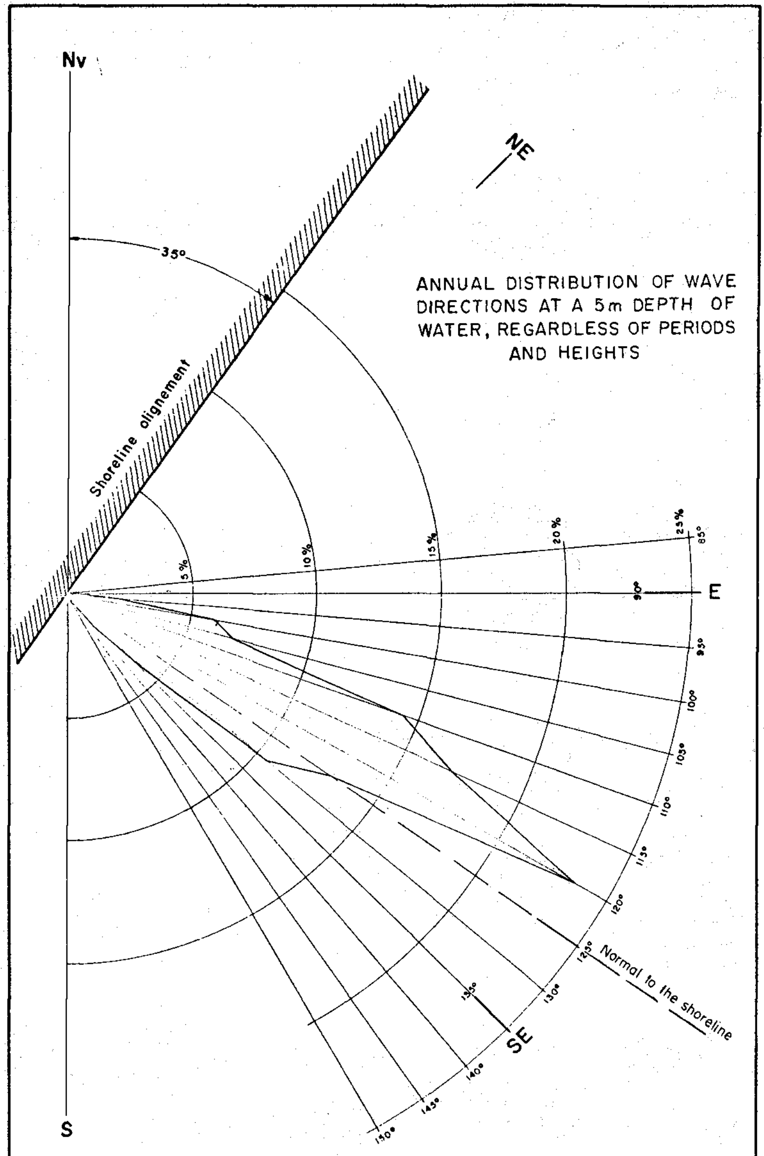

Nv
NE
35°
ANNUAL DISTRIBUTION OF WAVE DIRECTIONS AT A 5m DEPTH OF WATER, REGARDLESS OF PERIODS AND HEIGHTS
Shoreline alignement
5%
10%
15%
20%
25%
85°
90°
E
95°
100°
105°
110°
115°
120°
125°
130°
135°
140°
145°
150°
Normal to the shoreline
SE
S

FIG. 6

coefficient was taken as 0.004 (smooth beach). Incidentally, it was noticed that the transport capacities as calculated by Castanho's method are very little sensitive to the values adopted for the beach roughness coefficient.

Bijker's method essentially consists of assessing the increase due to the presence of waves in the transport capacity of a littoral current. As the only littoral current along the Sergipe coast is the longshore current brought about by the incoming oblique waves themselves, the "reference" current used in the application of Bijker's method was the longshore current as given by the Eagleson formula for idealized conditions [8]. Such ideal conditions are a reasonable approximation of the Sergipe shore.

The seaward boundary for applying Bijker's method was the -6m contour as it had been established by the radioactive-tracer experiment and done by Bijker himself in his calculations for the Queensland coast in Australia [6], [7].

Unlike Castanho's, Bijker's method is rather sensitive to the value adopted for the apparent bed roughness (half the ripple height) in the logarithmic formula for the Chezy coefficient. The value adopted for the apparent bed roughness was r = 0.17m which is the same value as used by Bijker himself in his calculations for Queensland [6], [7]. The geometry and exposure of the Sergipe coast can be taken as fairly similar to that case.

Caldwell's formula was used in metric units, and the total energy of the breakers was determined by solitary-wave theory.

IV) THE RESULTS OF THE COMPUTATIONS

The following table summarizes the results of the littoral-drift computations for the whole year.

TABLE I

Method	Total annual volumes of littoral drift in both shoreline directions (in $10^3 m^3$)	Percentages of total volumes in each shoreline direction %	
		NE-SW	SW-NE
Caldwell	826.8	80.8	19.2
Castanho	785.8	86.0	14.0
Bijker	757.1	83.3	16.7

Bearing in mind all the approximations contained in the computations, the three methods are seen to agree in this particular case to all practical purposes. They predict a total annual volume of littoral drift in both shoreline directions of the order of $800000 m^3$ per year. There is also a fair agreement as to the distribution of the annual volume in each shoreline direction. The dominant drift would be southwestward and amount to about $660000 m^3$ per year.

However, the three methods do not agree as to the variation of littoral drift over the year for the same waves. This fact is brought out by Fig. 7 which pictures the variation of the total monthly values of littoral drift in both shoreline directions throughout the year for each method. It becomes apparent that Castanho's method predicts a heavier littoral drift during the summer months. Caldwell's formula shows a more even distribution of littoral-drift volumes throughout the year. Bijker's method also predicts a heavier littoral drift during the summer months, although the dominance over the winter months is not so marked as according to Castanho.

Bijker's and Castanho's methods agree in that the month with the heaviest littoral drift is January (a summer month in the Southern Hemisphere). According to the Caldwell formula July (a winter month) would have the heaviest littoral drift.

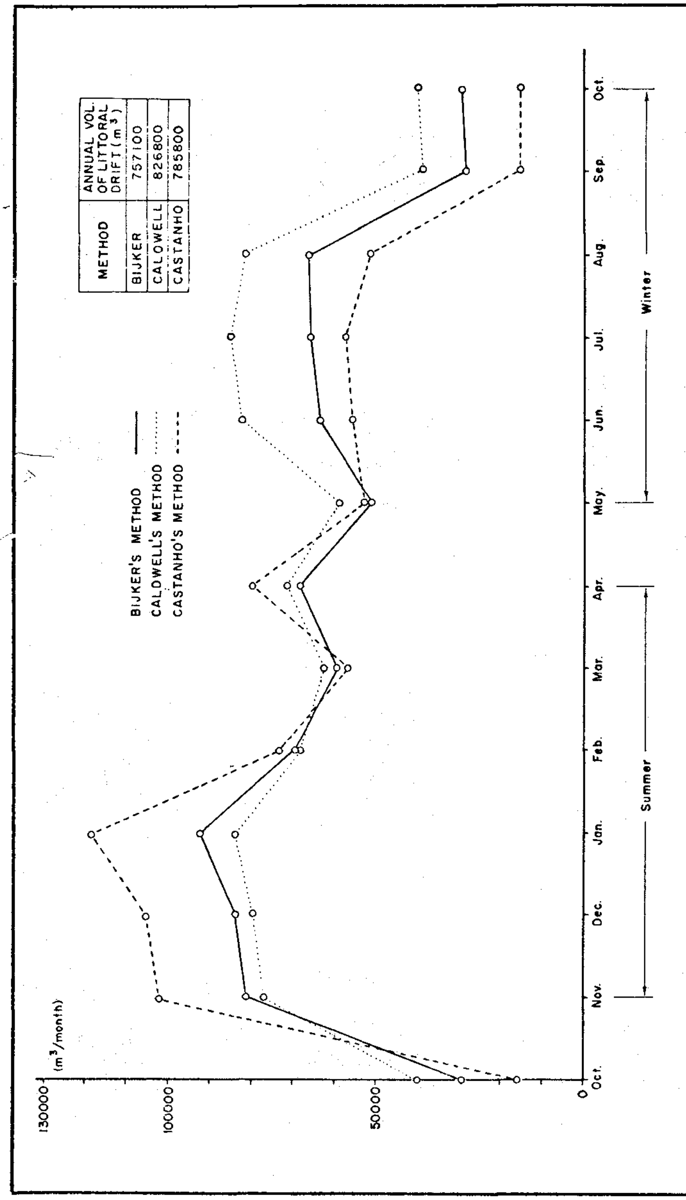
On the order hand, Bijker's and Caldwell's formulae agree in that April, September and October would be the months during which the direction of the net littoral drift would be the reverse of the dominant direction over the year (NE to SW). According to Castanho's method only in May the net littoral drift would be directed from SW to NE.

The agreement between the three different methods for the total annual results should be regarded as fortuitous, due to peculiar features of each method and of the wave climate off Sergipe. The same agreement may not be expected for a different wave climate.

The wave periods off Sergipe are short, and their range of variation throughout the year is small. As a result, the values of deep-water wave steepness are high most of the time. This causes the angle of wave attack at breaking depth (α_b) to be the main factor in determining the changes in the transport capacity of the waves over the year.

It was noticed that for α_b values below a certain limit, the transport capacity as predicted by Castanho's method is consistently smaller than the ones predicted by the other two methods. The reverse is true for α_b values above another limit. In the Castanho-Bijker comparison the critical values are 6^o and 14^o for the Sergipe coast. In the Castanho-Caldwell comparison the two critical values coincide at about 12^o.

It so happens off Sergipe that the summer waves are lower than the winter waves but in the summer the angles of wave attack are greater than in winter. As a result, a compensation effect makes the three different methods predict about the same value for the total annual volume of littoral drift, although they also predict different variations of littoral-drift intensities throughout the year.



VARIATION OF THE TOTAL MONTHLY VALUES IN BOTH SHORELINE DIRECTIONS OVER THE YEAR

FIG. 7

V) THE CUBATURE OF DEPOSITS IN THE DREDGED CHANNEL

The channel accross the Aracaju bar has been dredged to a depth of 8m with a bottom width of 80m. After the dredging reached completion the channel was surveyed in December 1971, August and December 1972. The cubature of the deposits has been made by the junior author, and particular care has been taken to check on that the side slopes had already reached equilibrium in the earliest survey available.

The following table displays the results of the cubature and the littoral-drift computations for the same lengths of time.

TABLE II

Method \ Time Interval	Dec 71 - Aug 72 (in $10^3 m^3$)	Aug 72 - Dec 72 (in $10^3 m^3$)	Total for the year (in $10^3 m^3$)
Caldwell	594.4	232.4	826.8
Castanho	582.4	203.4	785.8
Bijker	548.3	208.8	757.1
Cubature	336.0	228.0	564.0

The predicted results were expected to exceed the cubature results for two reasons:

a) the computations had been carried out with the significant wave heights;

b) some of the littoral-drift material may not stay in the channel as deposits since it may be flushed out offshore or brought back to the downdrift coast by the tidal flow from the estuary.

The relative errors for the whole year were respectively + 46.6% for Caldwell's formula, + 39.3% for Castanho's method and + 34.2% for Bijker's method. However, for the August 72 - December 72 time interval the agreement between predicted and actual results was remarkably good.

The time intervals between successive surveys were not short enough to enable an assessment of which computation method had best predicted the history of the deposits. In particular, the actual time intervals (December 71 - August 72 and August - December 72) between the successive surveys include both summer and winter months.

Obviously the agreement of the three methods for the August - December 72 time interval is due to the peculiar features predicted by each method for the variation of littoral-drift intensities over the year as shown in Fig. 7.

It is not possible to give a definite explanantion of the agreement between predicted and actual results for the particular time interval August - December 1972. However, the most likely explanation is that the actual wave action during that time was more severe than in the corresponding time interval of the standard year used for the computations.

VI) CONCLUSIONS

1) For the particular wave climate off the coast of Sergipe, in the Northeast of Brazil, Caldwell's, Castanho's and Bijker's methods lead to practically the same total annual volumes of littoral drift in both shoreline directions: about 800000 cubic metres per year.

2) The three methods also practically agree for the annual volumes in each shoreline direction.

3) However, the three methods do not agree as to the variation of littoral-drift intensities over the year for the same waves.

4) The agreement for the total annual volume of littoral drift must be considered as fortuitous, due to the particular features of each method and of the wave climate off Sergipe. It may not be expected for a different wave climate.

5) A comparison has been made between computed volumes of littoral drift and deposits in a dredged channel accross the Aracaju bar for the same lengths of time. The relative errors for the whole year were respectively + 46.6% for Caldwell's method, + 39.3% for Castanho's method and + 34.2% for Bijker's method. However, for the August 72 - December 72 time interval the agreement between predicted and actual results was remarkably good.

6) Even when only monochromatic waves are taken into account, the state of the art of littoral-drift evaluation remains open to research and further improvement.

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