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PORT OF BRISBANE SILTATION STUDY

Third Report: Tidal propagation in the Brisbane River in the dry-season

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June 1978
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INTRODUCTION

1 In January 1977, the newly formed Port of Brisbane Authority (PBA) commissioned the Hydraulics Research Station (HRS) to investigate the causes of siltation in the shipping channels in the Brisbane River. HRS recommended the use of mathematical model techniques to predict the effect of engineering works associated with the construction of the new port developments at Fisherman Islands and proposed changes in dredging practices on siltation in the river.

2 This report describes the analysis of tidal records to determine the main features of tidal propagation in the river. The report also describes the application of a standard one-dimensional mathematical model to simulate tidal flows in the estuary. A good understanding of tidal motion in an estuary is an essential prerequisite to a study of sediment transport within it. The model was used for the following purposes:–

i) To determine the effective roughness of the channel.

ii) To determine the relative strengths of the diurnal and semi-diurnal tidal currents.

iii) To hindcast the pattern of tidal currents during the dry-season survey in August 1977.

iv) To quantify the distribution of flows between the New and Old Bar Cuttings.

v) To hindcast the tidal discharge flowing through the swing basin at Fisherman Islands during the float tracking exercise in May 1977 to be used as a boundary condition for the two-dimensional, in plan model proving tests.

THE TIDAL REGIME

3 The tidal regime at the mouth of the Brisbane River is a mixed one with significant diurnal and semi-diurnal constituents, shown in Table 1. The amplitude and phase of the main components of the tide at the West Inner Bar Cutting Beacon are given in Table 1. The M_2 semi-diurnal constituent is the largest one with an amplitude of 0.724 m. The next largest component is the K_1 diurnal constituent with an amplitude of 0.216 m. The S_2 constituent is only 0.194 m, indicating a relatively small variation (5:9) in the tidal range during the neap-spring cycle.

Tidal level observations

4 The PBA operate automatic tide gauges at four sites in the port area at the West Inner Bar Cutting Beacon, Cairncross Dock, Newstead and at the Port Office; all shown in Fig 1.

5 In 1974, the Department of Physics of the University of Queensland installed five temporary automatic tide gauges in the upper reaches of the estuary. HRS was supplied with several months of records made in 1974 from all nine gauges in the form of the original pen traces reduced on to microfiche.

6 A similar set of tidal observations was made during this study in the dry-season survey on 15 and 16 August 1977 (Ref 1).

Species analysis

7 A species analysis was carried out on the tidal observations collected by the University between 20 June to 20 July 1974, when all the gauges were operating more or less simultaneously and the fluvial flow was negligible.

8 Species analysis, a variation of Fourier analysis, can be used to isolate the different harmonic components that make up the tide at a particular location (Ref 3). The frequencies of the main species are determined by the orbital motions of the earth and the moon about the sun. The coefficients (amplitude and phase) of a chosen set of harmonics can be determined from a suitably long record of tidal levels (or currents). Their values can be used to quantify the main features of tidal motion in a particular estuary. The coefficients can also be used to re-synthesize or predict the tidal motion by superposing the individual constituents as follows:–

9 The vertical tide at a point is defined as the sum of a set of harmonics

$$\eta(x,t) = Z_0(x) + \sum_{i=1,n} a_i(x) \cos(\omega_i t - \phi_i(x))$$

where

$Z_0(x)$ is the mean tide level
$a_i(x)$ is the amplitude of the component i
ω_i is the frequency of the component i
t is the time
$\phi_i(x)$ is the local phase of the component i
n is the total number of harmonics

10 The types, names and frequencies (f) of the seven main tidal harmonic constituents which were used to describe the tidal motion in the Brisbane River are as follows:–

Type	*Name*	*Frequency (degrees/h)*
Two-weekly	MS_f	1.016
Diurnal	O_1	13.943
	K_1	15.041
Semi-diurnal	N_2	28.440
	M_2	28.984
	S_2	30.000
Shallow water constituent	M_4	57.968

11 The length of record required for an accurate determination of the coefficients of a given constituent is governed by the following conditions:–

i) It should contain a whole cycle of the constituent being analysed.

ii) It should contain the whole of any beating cycle between pairs of constituents ($T = 360/\Delta f$).

The lengths of the tidal records available varied between 15 and 30 days. The results from the analyses of the shorter records, shown in Table 2, contained inaccuracies arising from the fact that the second condition was not fulfilled for the N_2 and M_2 constituents. These constituents beat every 661.3 hours (27.55 days). However, the errors were not thought to be excessive since the shortest record was long enough for these two components to drift apart by 180^o; the absolute minimum to separate the components.

12 All the records appeared to be of a high quality with the exception of the Newstead gauge where the chart had been incorrectly positioned on the drum. The species analysis showed further inconsistencies in the tide recorded at Cairncross Dock, see Fig 2. At this location, the amplitudes of the constituents appeared to be correct but the phases indicated a significant timing error in the record. The analysis of the 30-day record observed at the West Inner Bar Beacon (Table 1) agreed with the figures

published by the Institute of Oceanographic Sciences (IOS) based on a complete analysis of a full year's record in 1973.

13 The "g-phase" in Fig 2 refers to the phase of the various components at the beginning of the century (1900). The "local phase" in Fig 3 refers to the phase at the time of the observations, or on the date of the re-synthesis of the tide. Local phases can only be compared for observations or calculations covering the same period. The g-phase should be the same regardless of the date of the observations of a particular analysis.

14 The second short set of simultaneous tidal level observations made between 15 and 16 August 1977 (Ref 1) was subjected to a Fourier analysis to determine the amplitudes and phases of the effective diurnal tides (Z_1), semi-diurnal tides (Z_2) and quarter-diurnal tides (Z_4), shown in Fig 3. The effective periods were artificially prescribed as 25 hours, 12.5 hours and 6.25 hours, respectively. Z_0 refers to the mean tide level in both types of analysis.

15 A similar simplified analysis was applied to the tidal levels and tidal currents simulated by the one-dimensional mathematical model for the 48-hour period covering 15 and 16 August 1977, and the results are shown in Fig 3.

Propagation of the vertical tide

16 In the absence of frictional effects, the speed of propagation of a tidal wave, where the tidal range is small compared to the mean depth, is directly related to the square root of the depth:

$$c = u + \sqrt{gd} \qquad \text{....(1)}$$

where
d is the mean water depth
g is the gravitational constant
u is the water velocity

The results of the analysis of the 1974 tidal observations show that the rate of propagation of the tide is about 12 m/s through the port area, which is consistent with a mean depth of about 11 m. Upstream of the Port Office, the rate of propagation is considerably reduced to a speed of about 5 m/s, indicating a strong frictional effect, which is confirmed by the fact that the mean depth of water is about 6 m which corresponds to a frictionless speed of 8 m/s.

Shallow water effects

17 If the range of the tide is appreciable compared to the mean depth of water and the tidal currents are strong, the speed of propagation of high water will be significantly faster than that of low water and the tide will become progressively more distorted in the landward direction. This distortion, which takes the form of a more sharply rising flood tide and a gradually falling ebb tide, is called the shallow water effect. It is quantified by the magnitude of the M_4 constituent of the tide. The relatively small rate of growth of the M_4 constituent within the Brisbane River estuary is shown in Fig 2, and indicates relatively weak shallow water effects and hence a more or less sinusoidal tide throughout the length of the estuary.

Diurnal and semi-diurnal constituents

18 The amplitudes of the two diurnal components, O_1 and K_1, remain almost constant throughout the estuary, which is typical of a long period component. The main semi-diurnal component, M_2, increases by about 11% between the West Inner Bar Beacon and the Port Office. This amplification

is almost certainly caused by the rapid decrease in the cross-sectional area of the channel in the lower estuary. Upstream of the Port Office, the M_2 component gradually decreases as far as Moggill, where it is about 14% less than at the West Inner Bar Beacon. This damping of the main constituent is an indication of considerable energy dissipation in the middle reaches of the estuary.

Resonance effects

19 The two smaller, and almost equally sized, semi-diurnal components, N_2 and S_2, remained almost constant in amplitude throughout the length of the estuary. This is fairly unusual because frictional effects tend to damp out the smaller semi-diurnal components more rapidly than the main semi-diurnal component. However, the length of the estuary is about 100 km which is close to the first resonant length for all the semi-diurnal components. This resonant condition, shown in Fig 4, occurs when the length of a tidal compartment is approximately one quarter of the effective wave length of the tidal constituent ($L = T\sqrt{gd} = 400$ km). In this case the magnitude of all the semi-diurnal components will tend to increase in the landward direction. The exponential decrease in the cross-sectional area in the landward direction tends to exaggerate the resonant condition. The dissipation of energy by frictional resistance in the middle reaches of the tidal river appears to be above a critical value that allows resonance to occur. This means that the tidal range in the middle and upper reaches of the estuary is very sensitive to the effective roughness of the channel.

20 The analysis of the short term tidal observations made during the dry-season survey on 15 and 16 August 1977 showed the same trends for the diurnal, semi-diurnal and quarter-diurnal tides, see Fig 3, except that these latter observations showed an increase in the tidal range in the last 20 km of the tidal river which was not apparent in the 1974 observations. This inconsistency deserves further investigation but it is unlikely to have any significant effect on our understanding of the tidal motions in the middle and lower reaches of the estuary.

21 The two-weekly MS_f component of the tide, which is generated by the non-linear interaction of the M_2 and S_2 components, has a negligible effect on tidal motion in the Brisbane River.

22 The mean tide levels, derived from the 1974 and 1977 observations and shown in Fig 5, show that the mean tide profile is almost flat in the port area and that it rises uniformly in the middle reaches and then flattens off at the head of the estuary at a level about 300 mm higher than at the mouth. The mean tide level derived from the 1977 observations at Moggill Ferry appear to be in error.

NUMERICAL SIMULATION OF TIDAL MOTION IN THE ESTUARY

23 HRS used the geometry data-set described in the previous report (Ref 2) as a basis for a standard bulk-flow type of numerical model which is commonly used to simulate and predict the gross features of tidal motions in an estuary (Ref 4). The model solved the cross-sectionally averaged equations of motion and continuity ignoring density variations in the estuary. It extended from the Outer Bar Cutting Beacon to Mount Crosby Weir. The Old Bar Cutting and Bremer River were included as separate channels. The vertical tide was assumed to have the same phase at the seaward ends of both the New and Old Bar Cuttings. The actual time lag between the tide at these two locations is probably about 5 minutes (Ref 5).

24 The input tide was synthesized using three approximate harmonic components (Z_1, Z_2 and Z_4) derived from a Fourier type of species analysis of the 48-hour record at the West Inner Bar Beacon between 15 and 17 August 1977. The model was set up to hindcast conditions during the dry-season survey on 15 and 16 August 1977. It was started from arbitrary initial conditions on 13 August 1977, so that it had time to settle down before the start of the survey period.

Determination of the roughness of the channel

25 The output from the model was analysed in terms of Z_1, Z_2 and Z_4 constituents because of the short length of the 'record' from the model. The longitudinal distribution of the roughness on the bed of the estuary was initially chosen to match the variation in the bed surface sediments. For example, the muddy reaches of the river were assumed to be effectively smooth. The values of roughness in the middle and upper reaches of the estuary were then altered until there was a satisfactory agreement between the model results and the observations as regards the general variations in amplitude and phase of the hypothetical diurnal, semi-diurnal and quarter-diurnal constituents. The final results are shown in Fig 3.

26 The rate of propagation and damping of the semi-diurnal component was sensitive to the amount of roughness on the bed. After several adjustments to the roughness distribution, the model simulated all the main features of the propagation of the vertical tide in the estuary and these are shown in Fig 6. When the model roughness values were transformed into equivalent Manning 'n' values, the optimum longitudinal distribution of bed roughness used in the model agreed with the 'n' values used by Cain (Ref 6 (Appendix C, Fig 8)) in his bulk-flow model of tidal flow in the estuary. This comparison is shown in Fig 7.

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left\{\frac{k_s}{14.8d} + \frac{2.51\nu}{4Ud\sqrt{f}}\right\}$$

$$n = d^{1/6}\sqrt{f/8g}$$

where
U is the water velocity (m/s)
d is the average hydraulic mean depth (m)
f is the Darcy Weisbach friction factor
ν is the kinematic viscosity of water (m^2/s)
n is the metric Manning coefficient
k_s is the equivalent spherical grain size roughness (m)

27 The importance of the effect of frictional resistance on the propagation of the tide can be gauged from the value of the average dissipation factor, D_S, when

$$D_S = \frac{f}{64} \cdot \frac{T}{d} \cdot U_{max}$$

where
T is the tidal period of the largest tidal constituent (s)
f is the friction factor of the channel
U_{max} is the typical maximum tidal velocity (m/s)

D_S is proportional to the ratio between the rate at which energy is dissipated by frictional resistance and the total energy of the tidal motion. A value of D_S of less than 2 indicates that frictional effects are relatively unimportant, and that the tidal motion is strongly influenced by inertia effects. A value greater than about 10 indicates that the frictional effects have a very important influence on the propagation of the tide.

Frictional resistance, caused by channel roughness or irregularities, flattens the peak tidal velocities and generally slows, distorts and dampens the propagation of the tide up an estuary.

28 The value of D_s in the Brisbane River estuary is about 0.3 in the Fisherman Islands reach, 0.6 in the upper port area, 4.0 in the mid reaches and 8.0 in the upper reaches. These values are listed with corresponding friction factors and velocities in Table 3.

Tidal propagation

29 The model successfully simulated most of the main features of the pattern of tidal propagation in the estuary when compared with the 1977 observations (Fig 3), except for details in the amplitude variations of the idealized Z_2 component in the upper estuary. However, some doubt must be cast on the results of the 1977 observations in the upper estuary (see Fig 3) because the variation of the amplitudes of the semi-diurnal tide simulated in the model agreed very well with the analysis of the true M_2 component derived from the 1974 set of observations, shown in Fig 2.

Mean tide levels

30 The model, which did not calculate the effect of longitudinal density variations, predicted an almost flat mean tide level profile in the absence of a significant fluvial discharge. However, when the model results were corrected using the observed mean-tide longitudinal density variation, they agreed very well with observations both in 1974 and 1977 (Fig 5). The density correction

$$Z_{0s}(x) = \int_0^x \frac{d(x)}{2\rho_0} \left| \frac{\partial \rho}{\partial x} \right|_x . \, dx$$

Tidal velocities

31 The cross-sectionally averaged tidal velocities simulated in the model were compared with the observations made at midstream at the seven fixed stations during the dry-season survey (Ref 1 (Figs 7-14)). The computed velocities were generally in phase with the observations. The magnitudes of the area-averaged velocities were sometimes half the value of the surface velocities and twice the value of the velocities near the bed.

32 As mentioned before, the computed tidal velocities were also subjected to a simplified type of species analysis based on Z_1, Z_2 and Z_4 components. The results of this analysis showed that the ratio of the semi-diurnal currents (Z_2) to the diurnal currents (Z_1) was about 6:1 (see Fig 8) compared to a ratio of about 3:1 for the vertical tidal amplitudes. This is to be expected because the semi-diurnal tide has twice the frequency and therefore generates a proportionally larger current for the same vertical variation in water level. The magnitude of the Z_2 current is fairly constant at about 0.5 m/s throughout the lower and middle reaches of the estuary. However, the local widening of the channel for the various turning basins has a proportional effect on the local velocities. For example, the amplitude of Z_2 component opposite Cairncross Dock is about 0.35 m/s compared to a value of 0.6 m/s at the Port Office.

Flow along the Old Bar Cutting

33 The results of the model showed that the Old Bar Cutting carried about 10% of the tidal flow into the estuary, so it has a small but significant effect on the tidal regime of the lower estuary.

Tidal discharges through the swing basin at Fisherman Islands

34 The model was also used to hindcast boundary conditions, ie tidal discharges for the two-dimensional, in plan model of flow in the swing basin at Fisherman Islands which is the subject of another report in this series.

DISCUSSION AND CONCLUSIONS

35 An analysis of the tidal regime in the Brisbane River during a period of negligible fluvial flow showed that it is mainly semi-diurnal in character as regards the strength of the tidal velocities, which are the main agency for scouring and transporting sediments. The diurnal tidal velocities account for only about 15% of the peak velocities during spring tides.

36 HRS suggest that the new, multi-layer tidal model, which will be used to simulate sediment transport processes in the estuary, should generally be operated on a simple semi-diurnal tidal cycle with a slightly magnified tidal range to allow for the effect of the diurnal tides. This mode of operation will reduce the running costs of the multi-layer model and expedite the proving and predictive stages of the sediment transport calculations.

37 The length of the tidal compartment is such that the semi-diurnal tide is close to the first resonant mode, with a tendency for the tidal amplitude to increase continuously in the landward direction. However, the middle and upper reaches of the tidal river are hydraulically rough causing a high rate of energy dissipation which damps the resonating semi-diurnal tidal constituents. This relatively high rate of dissipation of energy tends to keep mud in suspension in the middle and upper reaches of the estuary during the dry-season.

38 The one-dimensional, cross-sectionally averaged model was used to supply boundary conditions in terms of tidal discharges to the two-dimensional, in plan depth-averaged model of the Fisherman Islands swing basin. The 1-D model can also be used to predict the effect of changes to the geometry of the river channel on the main features of the tidal regime and on the evacuation of fluvial floods.

39 The model showed that the Old Bar Cutting channel conveys about 10% of the tidal prism of the Brisbane River.

ACKNOWLEDGEMENTS

40 The investigation, of which this report is the official Hydraulics Research Station account, was carried out in Dr T J Weare's division by Mr N V M Odd's section. The tidal analysis and mathematical modelling work was done by Mr P P Mayo. The simultaneous tidal observations made in 1974 were made available to HRS by the Department of Physics at the University of Queensland.

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TABLES

TABLE 1 MAIN TIDAL CONSTITUENTS AT THE MOUTH OF THE BRISBANE RIVER
(West Inner Bar Cutting Beacon)

Name	*Type*	*Amplitude (m)*		*'g-phase' (degrees)*	
		*1973/74**	*1974***	*1973/74**	*1974***
S_a	Annual	0.107	–	10.3	–
O_1	Diurnal	0.118	0.117	131.0	135.7
P_1	Diurnal	0.060	–	165.7	–
K_1	Diurnal	0.216	0.270	169.6	175.2
N_2	Semi-diurnal	0.143	0.154	263.6	268.8
M_2	Semi-diurnal	0.724	0.720	272.9	273.1
S_2	Semi-diurnal	0.194	0.157	301.6	315.1
K_2	Semi-diurnal	0.058	–	292.5	–

* IOS (Bidson) analysis data 26/9/73–15/10/74

** HRS analysis 30-day record

TABLE 2 TIDAL RECORDS FROM THE BRISBANE RIVER, JUNE–JULY 1974

Gauge location	*Distance from Entrance Beacons (km)*	*Length of record*		*Dates*	
		(days)	*(hours)*	*Start*	*Finish*
West Inner Bar Beacon	6.5	30	720	June 20	July 21
Cairncross Dock	21.9	30	720	June 20	July 21
Newstead	24.6	18	432	June 20	July 8
Port Office	31.7	21	504	June 27	July 18
Tennyson Power House	46.3	26	624	June 20	July 16
Darra Lime and Cement Wharf	56.2	30	720	June 20	July 21
Laguna Stud, Moggill	77.6	16	384	July 6	July 22
Kholo Creek	88.1	24	576	June 27	July 21
Church St, Tivoli, Ipswich	91.1	15	360	July 6	July 21

Note:– Accurate assessment of N_2 and M_2 components requires about 660 hours of record.

TABLE 3 TYPICAL DISSIPATION FACTORS FOR THE BRISBANE RIVER (DRY-SEASON)

Reach (km u/s from Entrance Beacons)	*Mean depth (m)*	*Typical friction factor*	*Average maximum tidal velocity (m/s)*	D_s
Fisherman Islands (7–10 km)	12	0.015	0.3	0.3
Port area (10–25 km)	11	0.015	0.6	0.6
Mid reaches (24–70 km)	6	0.045	0.7	4.0
Upper reaches (70–100 km)	3	0.070	0.5	8.0

$$D_s = \frac{f}{64} \cdot \frac{T}{d} \cdot U_{max}$$

where T = 12.5 hours

FIGURES

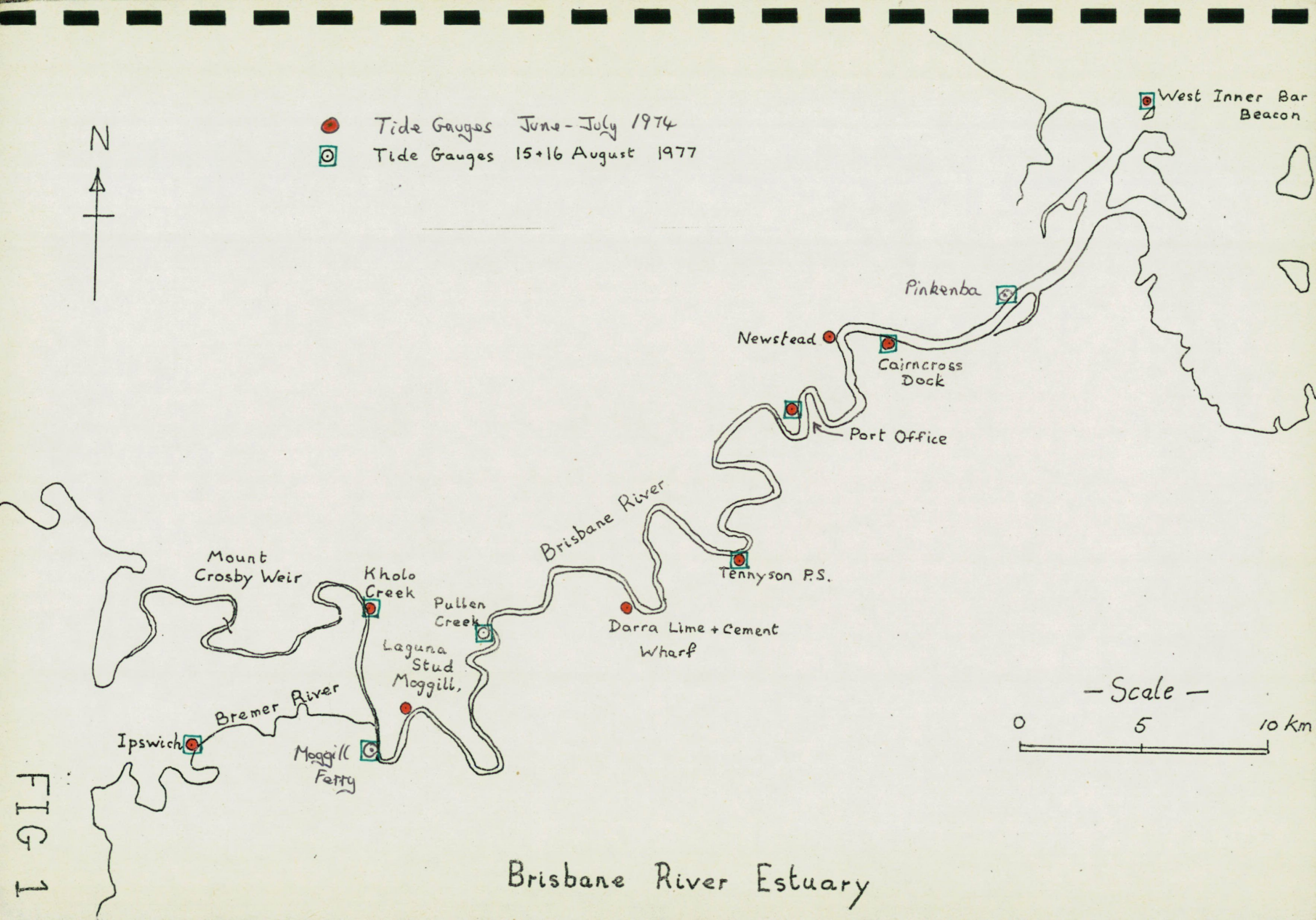
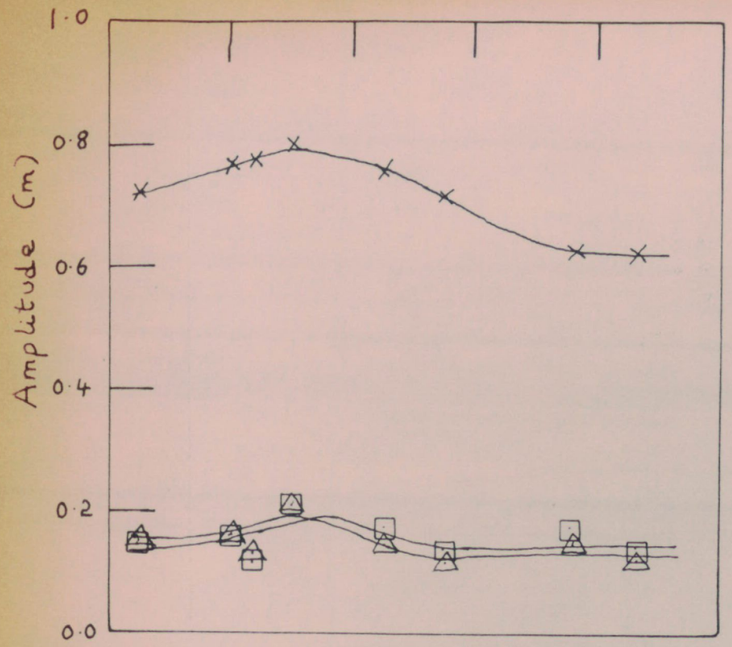
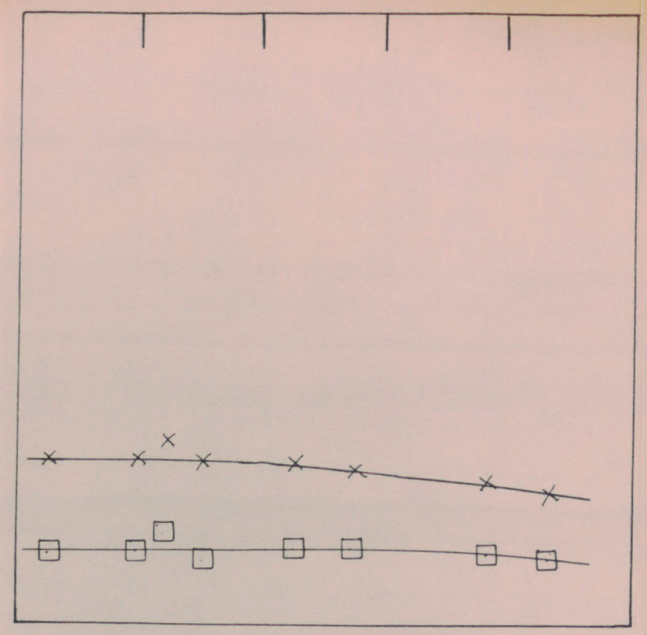


FIG 1

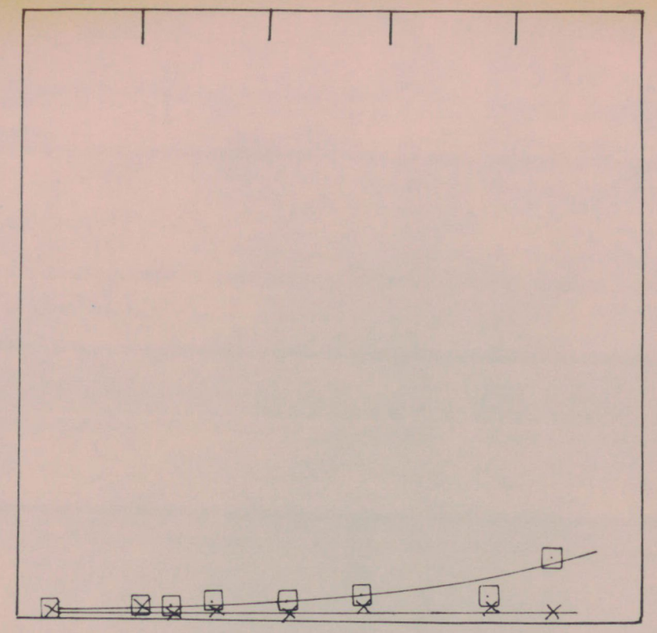
Brisbane River Estuary



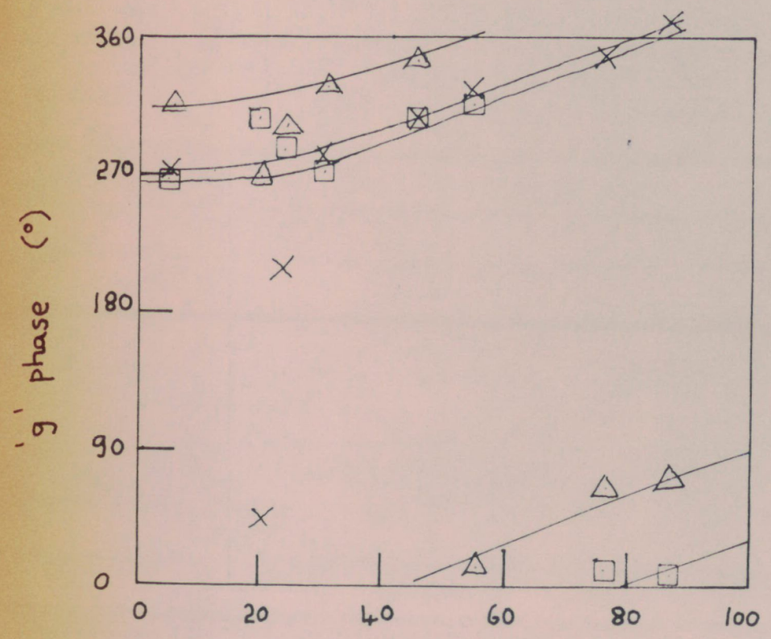
□ N_2 × M_2 △ S_2

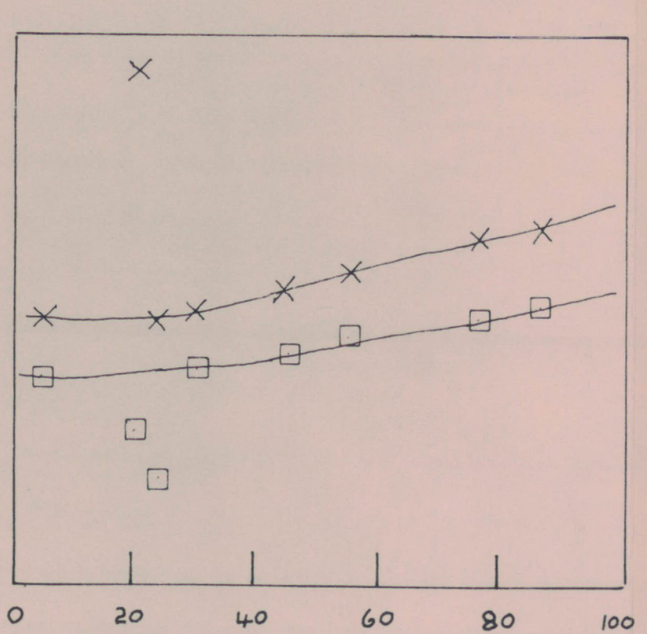


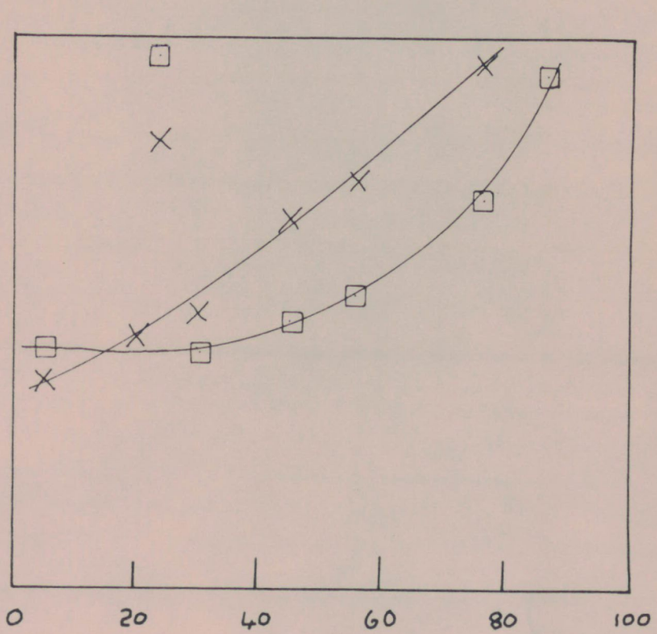
□ D_1 × K_1



□ M_4 × M_6





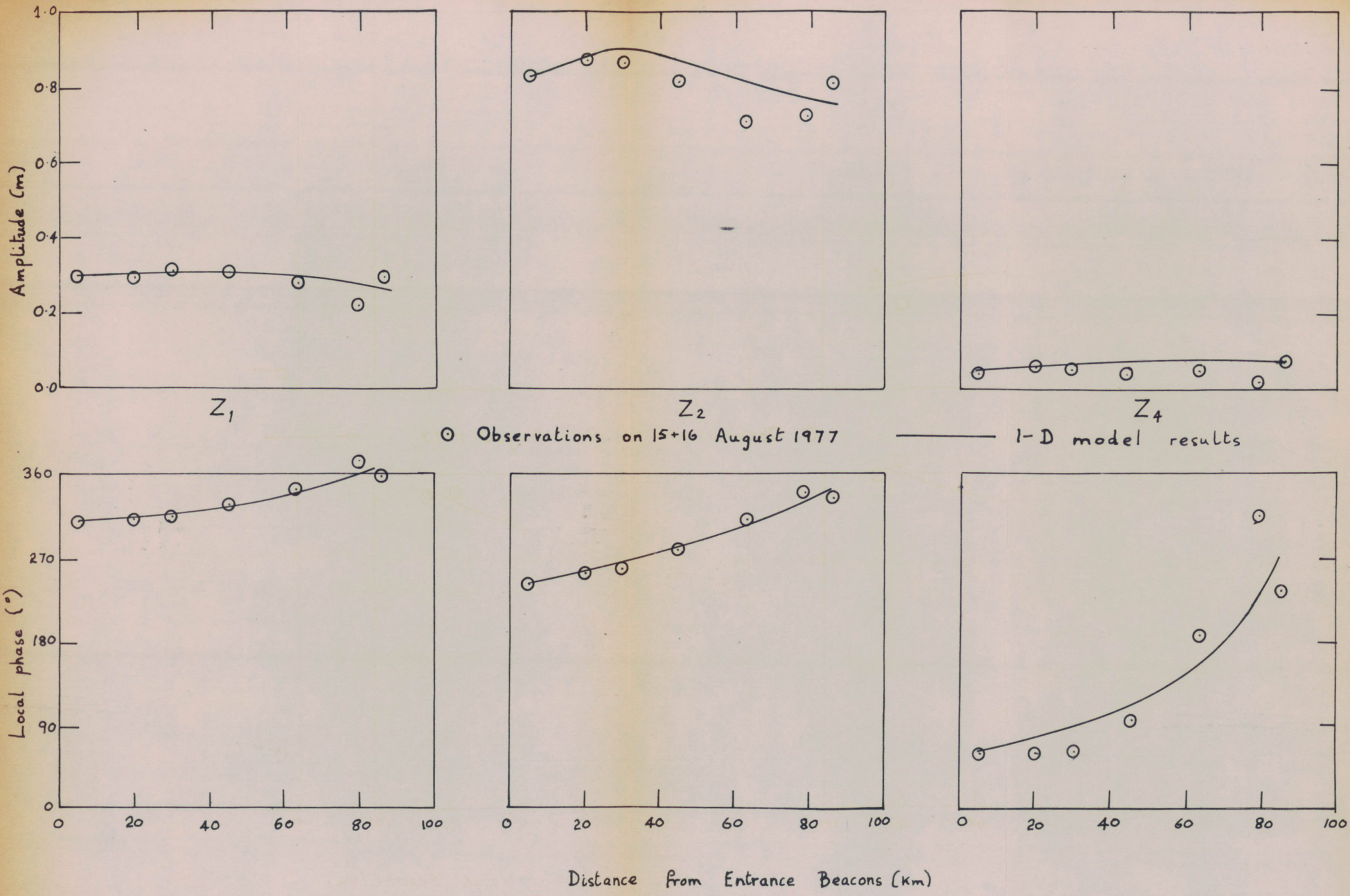


Distance from Entrance Beacons (km)

HARMONIC CONSTITUENTS OF THE VERTICAL TIDE

(1974 DATA)

FIG 2

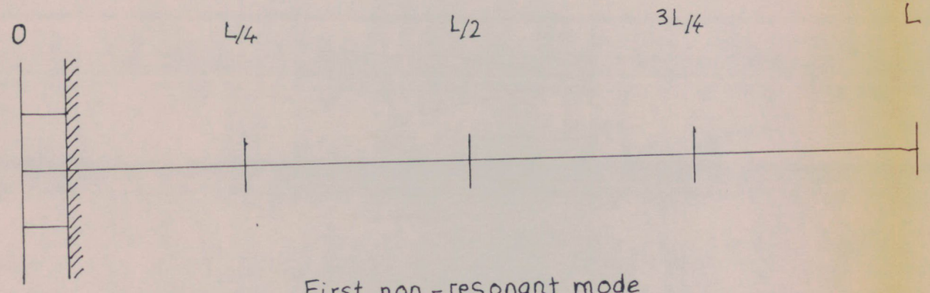


⊙ Observations on 15+16 August 1977 ——— 1-D model results

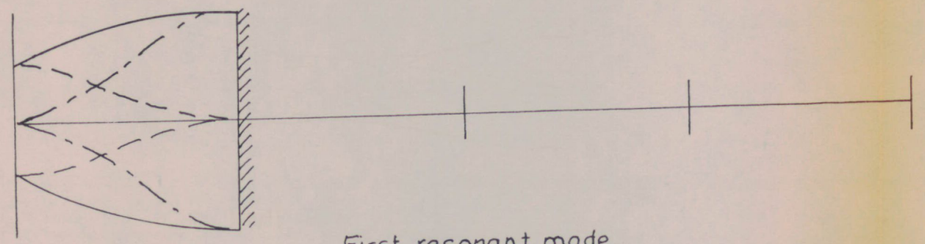
IDEALIZED HARMONIC CONSTITUENTS OF THE VERTICAL TIDE

(1977 data)

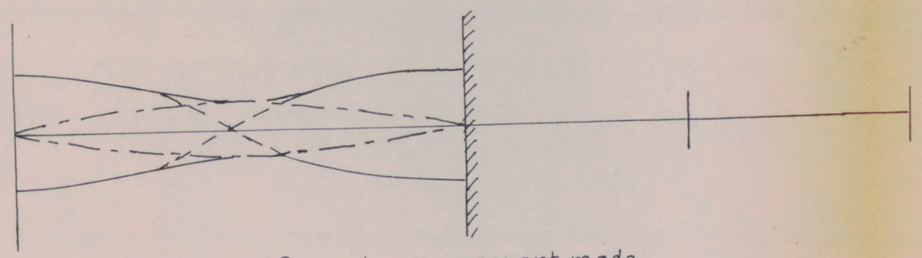
FIG 3



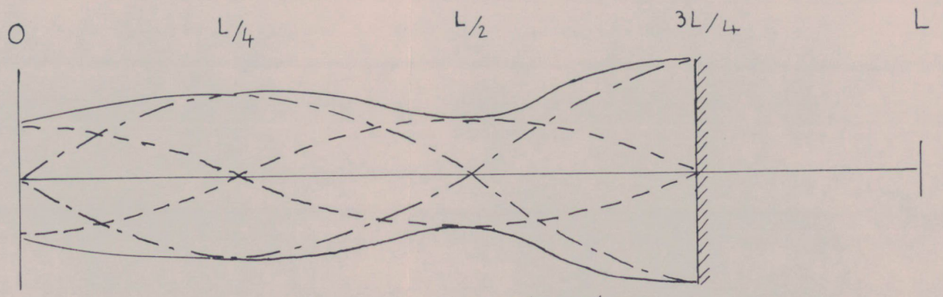
First non-resonant mode



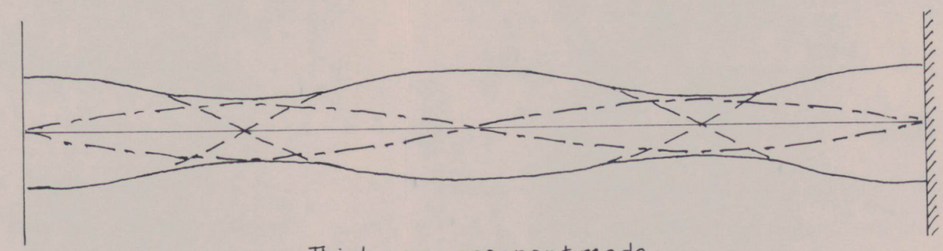
First resonant mode



Second non-resonant mode



Second resonant mode

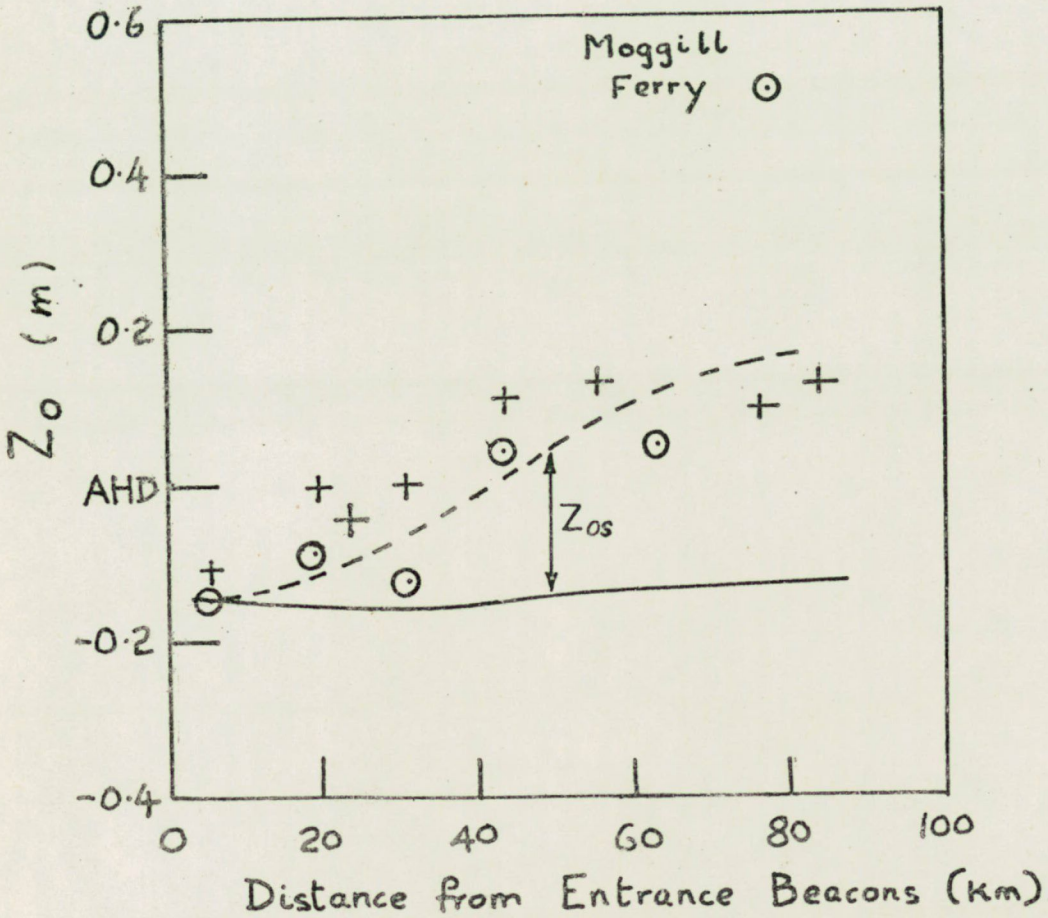


Third non-resonant mode

Legend
Loci of H.W and L.W. levels ——————
Typical simultaneous water level profiles within the tidal cycle
—— - —— Half tide
— — — — H.W. and L.W.

Resonant and non-resonant modes of motion in a uniform estuary

FIG 4



+ Long term observations 1974 (15 – 30 days)

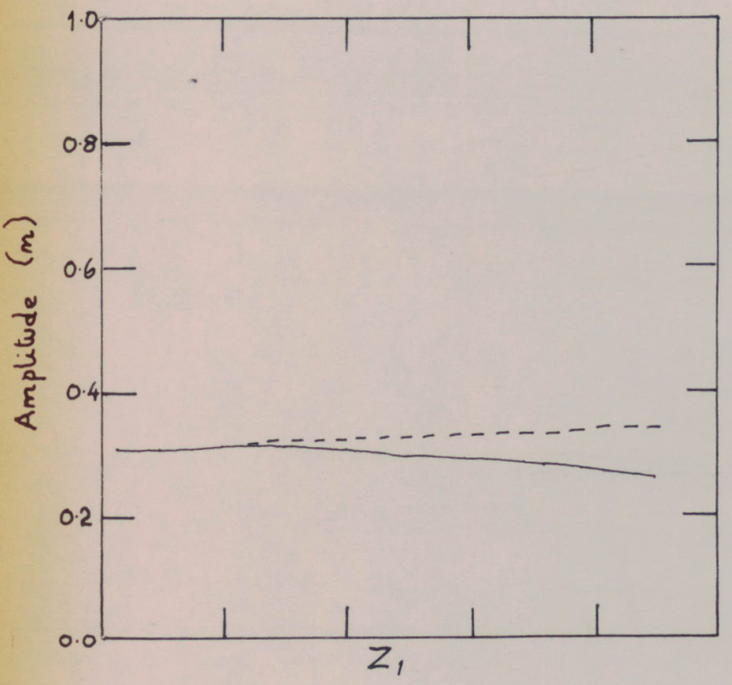
⊙ Short term observations 1977 (50 hours)

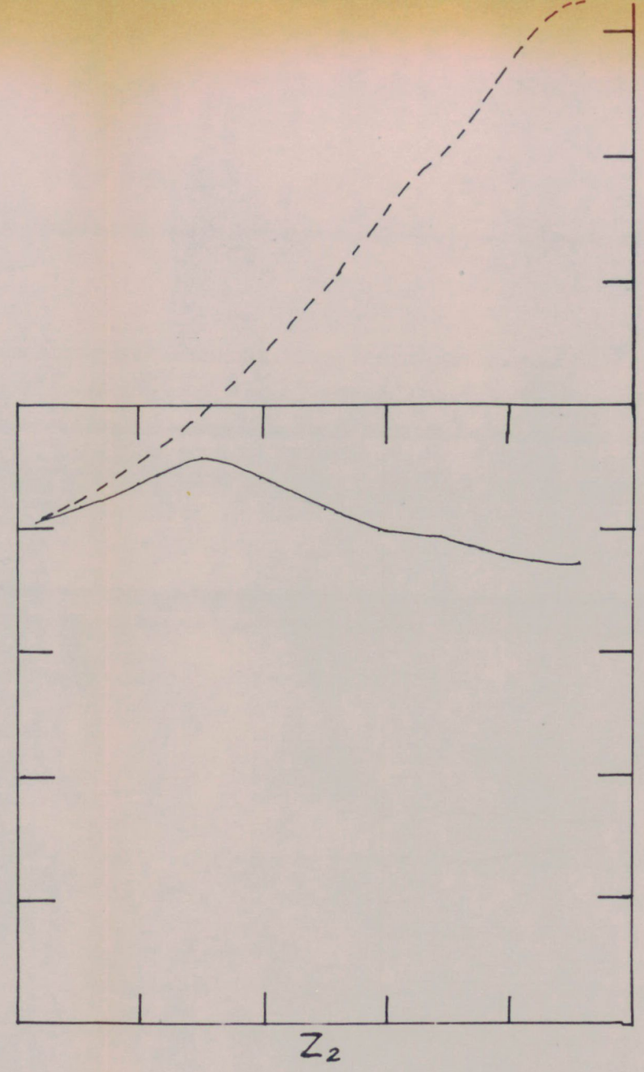
— Results from 1-D model (no density variations)

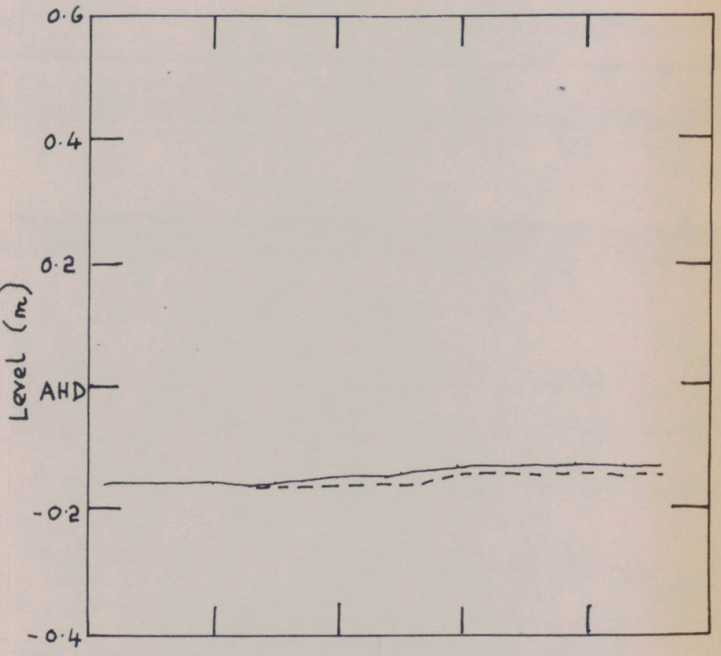
--- Results from 1-D model (with density corrections)

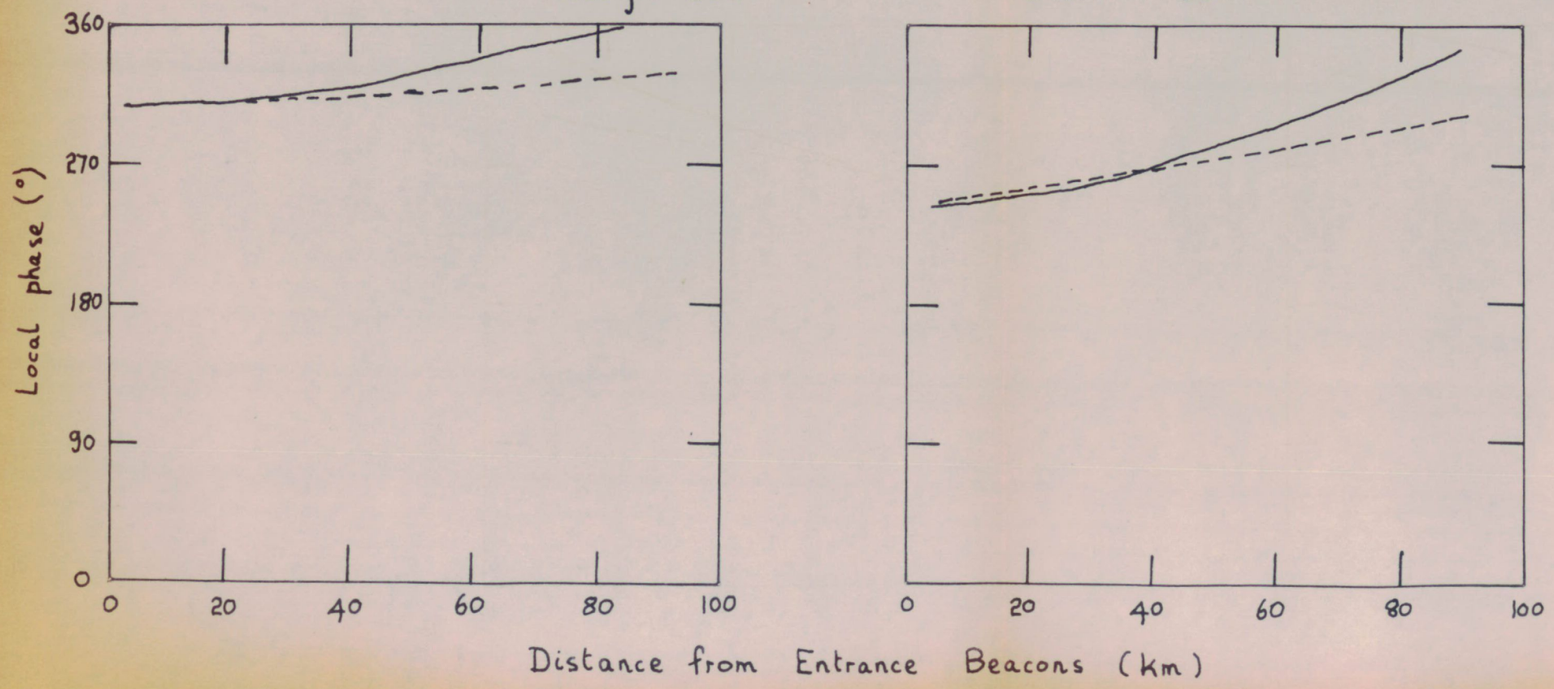
MEAN TIDE LEVEL ALONG THE BRISBANE RIVER

FIG 5



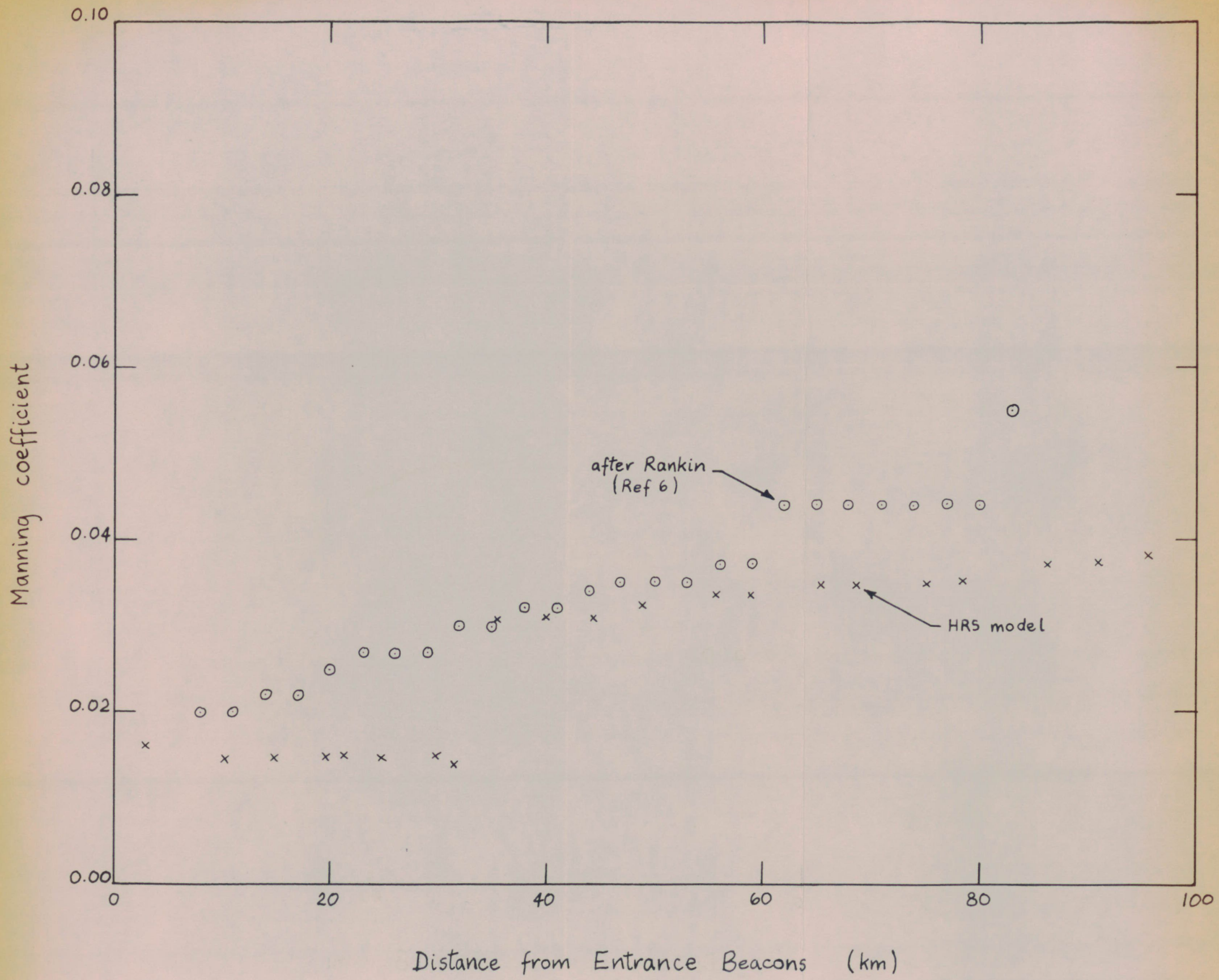






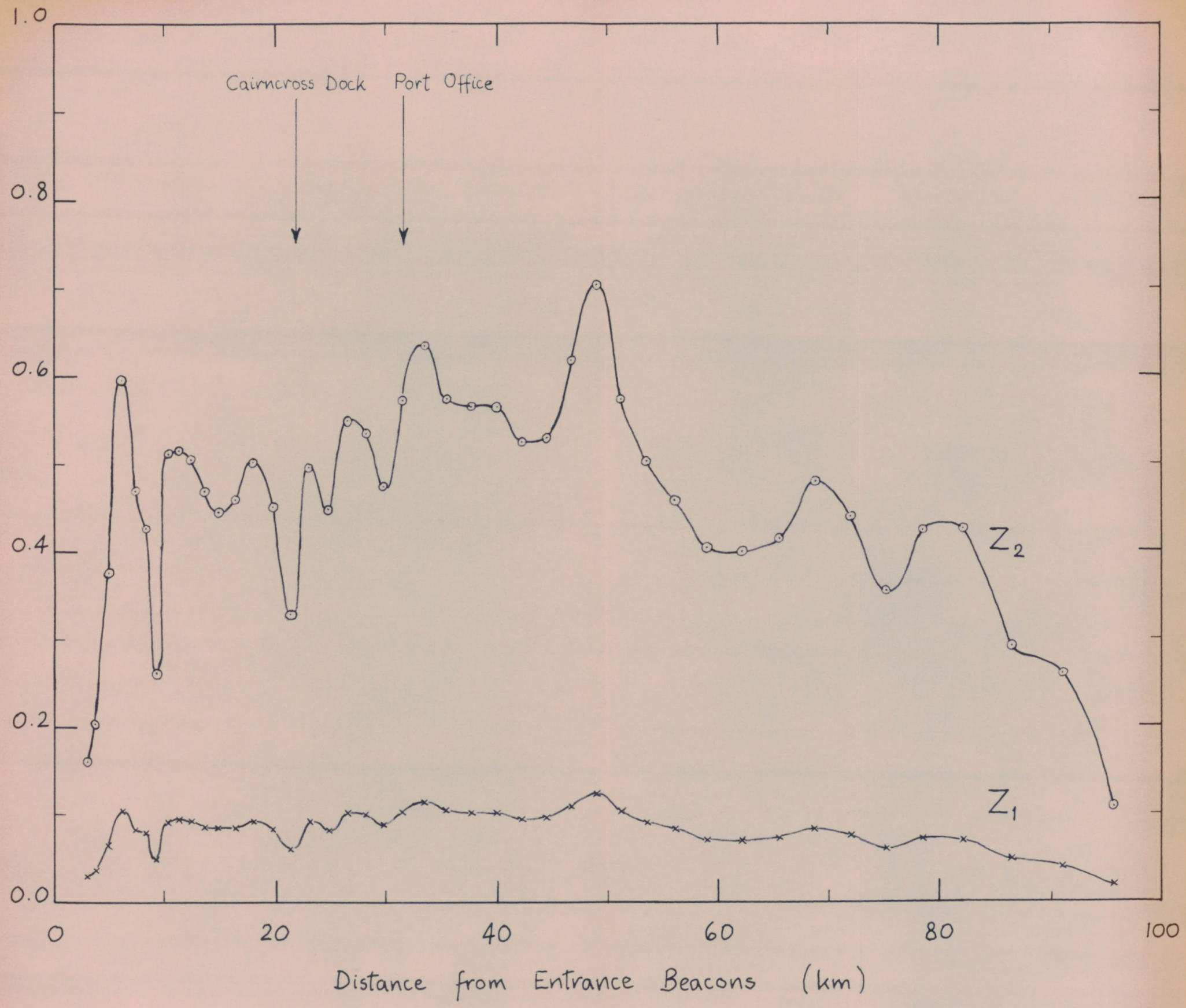
THE EFFECT OF CHANNEL ROUGHNESS ON THE PROPAGATION OF THE TIDE

FIG 6



DISTRIBUTION OF MANNING COEFFICIENTS

FIG 7



IDEALIZED HARMONIC CONSTITUENTS OF THE TIDAL VELOCITIES SIMULATED IN THE 1-D MODEL

FIG 8

551.353099432
HYDR
1978