Analytical Research of Littoral Transport Rate and Wave Energy Along the Putai Harbor site

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ABSTRACT

Due to the sheltering effect of the Wai-San-Ding Sand Barrier, the hydraulic condition of the putia harbor site is quite favorable. Since the relatively well-protected location of the Putai harbor area with regard to both waves and wind, no special navigational problems have to be envisaged.

The wave energy of the Putai harbor site is computed from the measured waves by considering the refraction effect down to breaking line. As the lack of wave records, the wind speed is used by applying the regression equations among the wave height, period and wind speeds, and then compute the wave height and period for obtaining the breaking wave energy. Therefore the total breaking wave energy (P_ℓ) of the whole year along the Putai harbor coast is summated.

The littoral transport rate (I_ℓ) is calculated from the mesh method by comparing the echo-sounding maps of two continuous different years. Therefore, the relationship of P_ℓ and I_ℓ is correlated in the Putai harbor site.

1. Introduction :

Pu-Tai harbor site area is located along the coast of Chia-Yi county, it faces to the Taiwan Strait, the bay area is about 900 hectoare. There is an large scale sand barrier 22 km long, 3-km wide, located on the NW of Pu-Tai bay, and then the barrier forms good wave sheltering effect to the bay.

The field records of wind condition at Pu-Tai from Nov., 1982 to Oct., 1983 show that the winter monsoon in December mainly blows the wind from NNE, N and NNW directions, etc., and with the stronger wind speed. In January, the prevailing wind directions are the same as those in December and totally 90% of occured frequency. The strongest wind occurs in N direction, and then in NNE direction also in February, wind overwhelmingly occurs in NNE, N, NNW directions which are in total 80% of occurred frequency. Wind in N direction occurs very frequently, but wind velocity of N and NNW directions is stronger. In March, wind comes more often from WNW, NW and NNW directions which totally reach up to 60%. Wind speed is highly reduced such that the occurrence of wind with speed stronger than 5 m/sec is only 17%. The wind in April occurs often from northerly direction, while in May, it comes from southern direction. From the long-term data, summer monsoon blows from April to August, the direction is from south, while wind speed is quite small. The prevailing wind direction is NNE to NNW blows during Winter monsoon from September to Next March.

From the wave measurement, the maximum wave height reaches 1.8 m, commonly wave height locates between 20 cm to 80 cm: while wave period is between 4 sec to 8 sec. Wave Rider is installed in the NW direction of the offshore area near-15 m deep; while KSK cassette type wave meter installed at the proposed harbor mouth. The measurement shows that wave height decays obviously from offshore toward harbor mouth; especially for the big wave, it decays almost 50%; while wave period becomes longer when wave reaches harbor area.

The distribution of significant wave heights and significant wave periods in June, 1983 indicates wave height appearing from 25 cm toward 1.25 cm; while wave period is from 2 sec to 8 sec; they are located in the lower value. They show during summer time, navigational condition is quite well in the Pu-Tai harbor area.

The measured wave distribution in December at the Pu-Tai Offshore (-15m) which locates the South-West of the promontory delta. Even in December, the significant wave height is in the range of 30 cm to 80 cm, the corresponding significant wave period is between 3 sec to 8 sec. In such case, the NE winter monsoon waves decay rapidly due to the sheltering promontory delta area. The measured results show that there is perfectly calm sea surface for ship anchoring in the Pu-Tai bay area.

The winter monsoon waves recorded at the proposed harbor area becomes smaller compared to the offshore zone; while period shows a little longer due to the scan from KSK cassette recorder has the tendency to collect significant wave and neglect the smaller wave, therefore, commonly two waves scan to record as one wave such that period becomes longer.

Pu-Tai proposed harbor entrance is located in the SW direction of Ueng Tau, and there is a wide natural sheltering Wai-Shan-Ding Barrier Island in the NW direction, therefore, it has a good condition for wave prevention from northerly direction. According to the records of the winds at Au-Ku meteorological station, the winds occur most frequent in the direction of NNE (40.2%) and then ENE (22.2%). The hurricane waves in SSW to W directions affect the site most significantly and therefore they are selected as the design waves of the proposed harbor which are 7 m of height and 12-15 sec of period. As the results from computer processing show, the waves in SSW direction diverge mostly (and with K=0.45) as they approach the vicinity of the proposed harbor site. Otherwise, the waves (with $T_{1/3}$=14.5 sec) in SW direction converge lightly at the same position. Generally speaking, the waves in other directions diverge as they approach the proposed site, therefore, the proposed site is convenient and suitable. Fig. 1-1 shows the wave refraction drawing of Pu-Tai harbor site with wave direction of SSW and wave period $T_{1/3}$=14.5 sec. It has the same decaying tendency with that of the field measured waves.

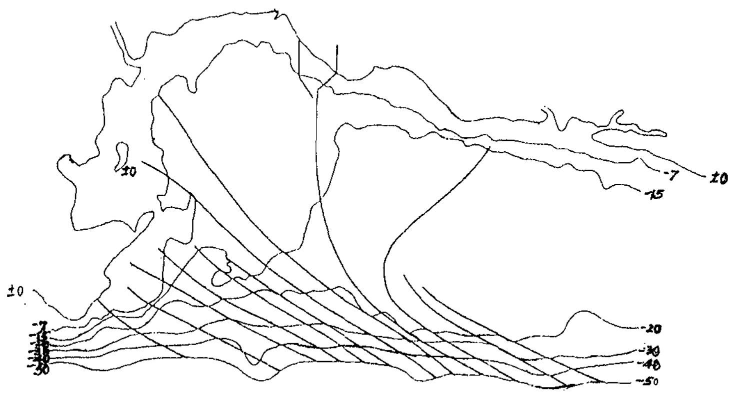

Figure 1-1 The wave refraction drawing of Pu-Tai site

ID : SSW T : 14.5 Sec

2. The calculation of the alongshore breaking wave energy: The wave data are recorded by the wave gauge at the depth -15m per 2 hours in 1983 at Putai offshore area.

The wave is affected by the effects of shoaling, refraction, bottom friction and percolation. By neglecting the effects of bottom friction and percolation.as wave is propagating toward the surf zone,therefore the breaking wave height is equal to H = HoKrKs where Kr and Ks are refraction coefficient and shoaling coefficient respectively. The mathematical representation is as follows

$$Kr = (Bo / B)^{1/2} \tag{2.1}$$

$$Ks = (Cgo / Cg)^{1/2} \tag{2.2}$$

where B is the separation of the wave rays and prefix "o" represents the characters of deep water. As the bottom slope is smaller than 1/10 then Kr and Ks could be calculated from the four equations derived by Chao,Y.Y.(1970) as follows

$$C^2 = \left(\frac{G}{K}\right) \tanh kh \tag{2.3}$$

$$\frac{d\theta}{ds} = -\frac{1}{c}\left(\sin\theta \frac{\partial c}{\partial x} - \cos\theta \frac{\partial c}{\partial y}\right) = -\frac{1}{c}\frac{dc}{dB} \tag{2.4}$$

$$H_o (C_g)_o B_o = H\, C_g\, B = \text{constant} \tag{2.5}$$

$$\frac{dB}{ds} - p(1)\frac{dB}{ds} + p(2)B = 0 \tag{2.6}$$

$$p(1) = \frac{1}{c}\left(\cos\theta\frac{\partial c}{\partial x} + \sin\theta\frac{\partial c}{\partial y}\right) \tag{2.7}$$

$$p(2) = \frac{1}{c}\left(\sin^2\theta\frac{\partial^2 c}{\partial x^2} - 2\sin\theta\,\mathrm{soc}\,\theta\frac{\partial^2 c}{\partial x \partial y} + \cos^2\theta\frac{\partial^2 c}{\partial y^2}\right) \tag{2.B}$$

where D is water depth, θ is the angle between X axis and wave direction, S is the distance along wave ray and C is the phase velocity. Use numerical method to get

$$D_{n+1} = D_n + \left(\frac{\partial D}{\partial x}\right)_n dx + \left(\frac{\partial D}{\partial y}\right)_n dy + \frac{1}{2}\left(\frac{\partial^2 D}{\partial x \partial y}\right)_n dx dx + \left(\frac{\partial^2 D}{\partial x \partial y}\right)_n dx dy + \frac{1}{2}\left(\frac{\partial^2 D}{\partial x \partial y}\right)_n dy dy \quad (2.9)$$

$$P_{n+1} = (4-2P_n^{(1)}\Delta S^2)/(2-P_n^{(1)}\Delta S)\ \theta_n - (2+P_n^{(1)}\Delta S)/(2-P_n^{(1)}\Delta S)\ \theta_{n-1} \quad (2.10)$$

The subscript "n" represents the value of the nth calculation, as shown in Fig.2.1, where X axis is taken parallel to the shoreline. Developing these numerical calculations to get "THE WAVE CHARACTER COMPUTING PROGRAM", (Hou etc., 1980) the wave characters such as Kr, Ks, H, Cg and θ could be found out at any water depth h=D. Since $\theta = \frac{\pi}{2} - \alpha$ as shown in Fig.2.1 then $(P_l)_b = \frac{1}{8}\rho G\ H_b^2 (c_g)_b \cos\theta_b \sin\theta_b$ is the alongshore breaking wave energy.

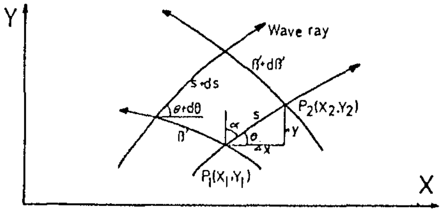

Figure 2.1 The diagram of the wave refraction.

Since there is no records of wave direction at -15m depth, the incident wave direction is found out by the above program using the deep water incident wave direction which is the wind direction as the wave gauge serves.

Consider only the waves which are moving onshore could cause littoral transporting. The waves which have the same incident direction are summed up. The root mean square value of their heights and the mean value of their periods are found out. Therefore, the total onshore acting waves are compiled to 8 equivalent waves which have the "rms" wave height Hrm , mean wave period T. This is because

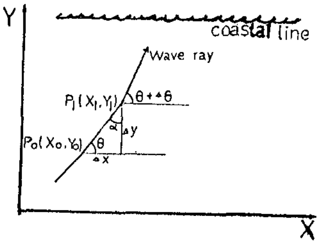

Figure 2.2. The diagram of the wave refraction.

$$(P_l)_b \propto H^2 \cos\theta\sin\theta \propto H^2 \sin 2\theta$$

$$\sum_{i=1}^{M} (P_l)_{bi} \propto \left(\sum_{i=1}^{M} H_i^2\right)\sin 2\theta = MH_{rms}^2 \sin 2\theta \quad (2.11)$$

Where M is the number of the waves which have the same wave direction , and Hrm is represented as

$$H_{rms}^2 = \frac{1}{M}\sum_{i=1}^{M} H_i^2 \quad (2.12)$$

To compute the alongshore breaking wave energy, the input data including the water depths of the grid points, the water depths and the coordinates of the incident points, the Hrm values and the T values of the equivalent waves with the incident wave direction at the depth -15m of the Putai offshore area, are all considered.

3. Computation Model between Wind and Waves

The paper is based on the winds and measured waves record, and then obtain their relationships. By using the 2nd order polynomial regression equation to work as the model for wind speed to compute wave height and wave period. From the above model and the measured wind records of the Pu-Tai Coast, the insufficient data could be supplied.

The computation procedure is described as follows.

1) To find out the statistical relationship between waves and winds for each month. By applying the records of wind speeds and wind directions, and the measured wave data from February to May., the relations among the wind speeds vs wave heights and wave periods correspondently at the same time could be reduced.

The wind speeds below 5 m/sec are neglected, since they have not significant effect to produce wave. To get rid of the small values of wind speeds and then compute the mean value, variance and correlation coefficient of each month. The statistical value is listed as the Table 3.1.

Table 3.1. Statistical Analysis of V, H & T.

	Wind Speed V(m/sec)		Wave Height Hrms(cm)		Correlation Coefficient of H vs T
month	Mean μ_v	Variance	Mean μ	Variance	TH
February	7.60	1.72	17.38	4.80	0.20
March	7.76	2.45	17.10	5.31	0.55
April	6.85	1.61	21.24	11.11	0.01
May	6.34	1.15	14.33	4.47	-0.20

In the Table 3.1, the mean is expressed as

$$U_x = \frac{1}{N}\sum_{i=1}^{N} X_i \qquad (3.1)$$

The variance is expressed as

$$\delta_x = \frac{1}{N}\sum_{i=1}^{N} (X_i - \mu_x)^2 \qquad (3.2)$$

and the correlation coefficient is expressed as

$$S_{xy} = \frac{\sum_{i=1}^{N} [(X_i - \mu_x)(Y_i - \mu_y)]}{\sqrt{\sum_{i=1}^{N} (X_i - \mu_x)^2 \sum_{i=1}^{N} (Y_i - \mu_y)^2}} \qquad (3.3)$$

From the above table, it is known that the correlation between wind and waves is so so perfect, the better one is in March, those of February and May are the next, the value in April is not so good correlation. The reason for fair correlation is due to the coastal geomorphological effect by the large Wai-San-Ding Sand Barrier, therefore winds and waves intrude into the Pu-Tai Bay area and show obvious refraction and energy diffusion. The effect of wave sheltering and shoaling is much complicated; while, in March, April and May, due to monsoon transitiond zone, the wind directions are changeable. For the avobe reasons, they cause the correlation coefficient be not so large. Except that, the time delay between wind and wave has some negative effect.

2) To find out the polynomial regression equations of wind speed vs wave height, and wind speed vs wave period. The correlations between winds and waves in February and in May are much better, and their wind directions are quite stable, therefore, February is considered as the base for computing the winter monsoon waves., while May is taken as the base for computing the summer monsoon waves. By using the least square method, and then the polynomial regression equations are obtained.

Let $X_1, X_2, X_3, \ldots, X_n$ as the n units of wind speed value.
$Y_1, Y_2, Y_3, \ldots, Y_n$ as the n units of corresponding wave height and wave period values.
as the constants of the m^{th} order polynomial regression equation.

$$X = \begin{bmatrix} 1 & X_1 & X_1^2 & X_1^3 & \cdots & X_1^m \\ 1 & X_2 & X_2^2 & X_2^3 & \cdots & X_2^m \\ \vdots & & & & & \vdots \\ \vdots & & & & & \vdots \\ 1 & X_n & X_n^2 & X_n^3 & \cdots & X_n^m \end{bmatrix}$$

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ \vdots \\ Y_n \end{bmatrix} \qquad A = \begin{bmatrix} A_0 \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{bmatrix}$$

The following relationship is obtained

$$X^T X A = X^T Y \qquad (3.4)$$

where X^T is the Transposed Matrix of X.

Solving "A" from EQ.(4), then the constants of the m^{th} order regression eguations of wave height vs wind speed, and of wave period vs wind speed correspondinglv of each month are attained.

Wave period and wave height could be calculated by Eg.(5) and Eg.(6).

$$H = a_0 + a_1V + a_2V^2 + \dots \dots + a_mV^m \qquad (3.5)$$
$$T = b_0 + b_1V + b_2V^2 + \dots \dots + b_mV^m \qquad (3.6)$$

where V is the wind speed.

From wind and waves data of February and May, by using the above method, the following regression eguations are obtained.

1. In February
   a. For the 1^{st} order regression equation (i.e. m=1)
      $H = 13.08 + 0.57V$ (3.7)
      $T = 11.12 + 0.10V$ (3.8)
   b. For the 2^{nd} order regression equation (i.e. m=2)
      $H + -3.73 + 4.95V - 0.27V$ (3.9)
      $T = 12.00- 0.39V + 0.014V$ (3.10)
   c. For the 3^{rd} order regression equation (i.e. m=3)
      $H = -29.87 + 14.93V - 1.48V + 0.047V$ (3.11)
      $T = 11.34 + 0.14V - 0.016V + 0.0012V$ (3.12)
2. In May
   a. For the 1^{st} order regression equation (i.e. m=1)
      $H = 11.15 - 0.76V$ (3.13)
      $T = 0.11 +0.55V$ (3.14)
   b. For the 2^{nd} order regression equation (i.e. m=2)
      $H = 52.53 - 11.00V + 0.75V$ (3.15)
      $T = -2.87 + 3.31V - 0.20V$ (3.16)
   c. For the 3^{rd} order regression equation (i.e. m=3)
      $H = 75.02 - 21.22V + 2.27V - 0.073V$ (3.17)
      $T = -18.31 + 10.33V - 1.24V + 0.050V$ (3.18)

   Units H : cm, T : sec, V : m/sec

   After comparing with each other, the 2^{nd} order regression eguations are suitable and selected as the computation model.

Analytical Results

To compute the other month's wind speed and convert to wave height and wave period, data are wind records of November and December of 1982, July and August of 1983 from Putai meteorology station and records of September and October of 1983 from Ao-Ku coastal station. By using the winter computation model, wind records of September, November, December and January are converted into wave heights and wave periods. While wind records of September, November, December and January are converted into wave heights and wave periods. Similarly, wind records of July and August are applied by using the summer computation model to get waves correspondently. After all waves are acquired, by using computation model of wave energy (Hou etc., 1984), then monthly wave energy are obtained and the results are shown in Table 3.2.

Table 3.2. Wave Energy monthly and daily in Putai Harbor Site

month / Wave Energy	July	August	Sept.	Oct.	Nov.	Dec.	Jan.	Unit
Monthly Wave Energy	14,960	14,530	12,670	13,380	13,470	18,250	16,830	ton-m / m-month
Daily Mean wave Energy	483	469	422	448	449	589	543	ton-m / m-day

To reduce wave energy of twelve months of the whole year, then they are shown in Fig.3.1 and Fig.3.2 and June shows heavy wave energy, since hurricane waves attacking, during this month, along the Putai coast.

4. Relationship between total Wave Energy and Littoral Transport Rate

Based on the analyzed result, it is found out the alongshore wave energy is 287,000 ton-m/m-yr, the corresponding littoral transport rate is 1.3×10^3 m^3/m-yr. The profile change of the Putai Bay area are shown from Fig4.1 to Fig.4.8. From the equation $I_\ell = K(P_\ell)_b$, the value of K is then become 3.5×10^{-3}. Therefore, the equation $I_\ell = 3.5 \times 10^{-3}(P_\ell)_b$ is applied to the Putai harbor site area. From the profile change of 1963, 1967 and 1980 they show that scour occurring along the Wai-San-Ding sand barrier due to supply of river sediment becomes less.

5. Conclusion and Suggestion

1) Applying the energy approach for unidirectional steady flow (Bagnold, 1963), derive out the relationship between the alongshore breaking wave energy and the littoral immered weight transport rate as $I_\ell = K(P_\ell)_b$. K is function of wave height, bottom slope, the grain size and the sediment transport pattern. It increases as the grain size decreases or it does either there exists are ocean current in the predominant littoral transport direction or under the action of the bigger waves. This reveals that the larger part of wave energy is supplied to transport sediment as the wave energy becomeslarger. This is shown by the empirical relationship $I_\ell = 0.154(P_\ell)_b$. But for a coast, such as the Taichung coast, where the oceanographic condition is so steady that the alongshore breading wave energy fluctuates slightly, the relationship between I_ℓ and $(P_\ell)_b$ could be written as $I_\ell = K(P_\ell)_b$, where K is constant. Then the Putai coast has the relation of $I_\ell = 0.0035(P_\ell)_b$. This equation could be applied for the coast of similar oceanographic conditions and beach characteristics to estimate the littoral transport rate. Such that the harbor planning and the shore protection could be based on.

2) Littoral transport study along the upstream and downstream of the Wai-San-Ding sand barrier (Hou, 1985) and the wave decaying and refracting of the Putai new port (Hou etc, 1984), has been deeply discussed. However, this paper deals with the measured data of wind speed, wind

direction and waves, then detail analyses are made to obtain the whole yearly alongshore wave energy. The littoral transport rate is obtained from the data of hydrographic survey. Therefore, the formula of $I_\ell = 3.5 \times 10^{-3} (P_\ell)_b$ is very appropriate for computing the littoral transport rate. The field measured data is very precious, since coastal area is widely surveyed, and very delicate, accurate instrument is used.

3) The model of wave height and wave period is deduced from wind speed. It's really a convenient and effective predict model for wind wave. Therefore, it could be applied and referred to ocean and coastal engineering use. However, the applicability of different wind conditions under different seasons need to be carefully considered.

4) The coefficient of littoral transport rate, K value, could be furtherly reconfirmed by comparing with the yearly dredging quantity of the Pu-Tai New Port. and then be modified.

5) As the shelf wind waves entering into the offshore due to the effect of Wai-San-Ding sand barrier, and then wave diffraction is shown, waves will turn around their direction, especially during winter season. Therefore, waves come from NNE and N directions will turn into NNW direction and then dissipate over the beach. It's really the features of local wind wave in the Putai harbor site. Therefore, the computation of wave energy along Putai coast, the offshore wave direction should be thoroughly considered.

6) Based on the calculation of wave energy along the Taichung harbor coast (Hou, etc, 1980) her yearly wave energy is sheltered by than that of the Putai harbor site. Since, the wave sheltering due to the Wai-San-Ding Sand Barrier, the offshore wave energy decays and decreases largely as it reaches the Putai harbor site.

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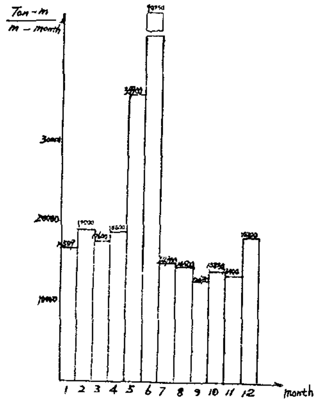

Fig.3.1 Monthly Mean Wave Energy of Putai Harbor (1983)

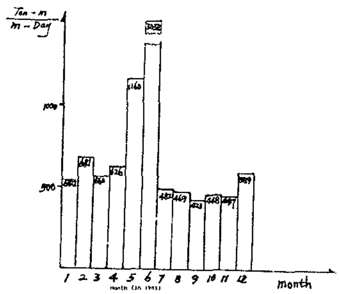

Fig.3.2 Daily Mean Wave Energy of Putai Harbor (1983)

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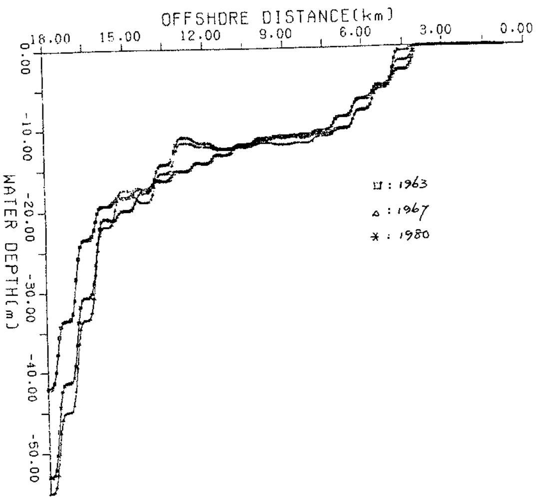

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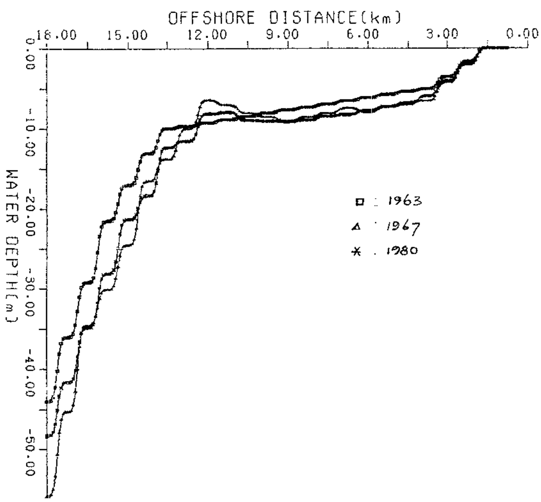

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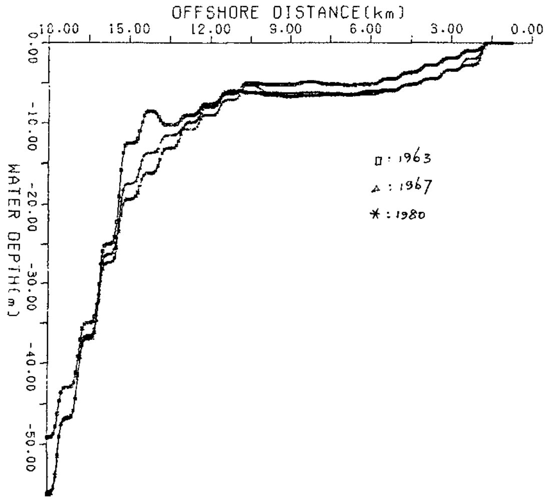

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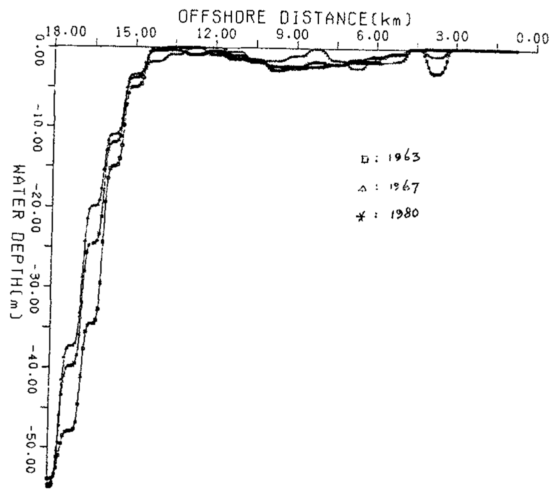

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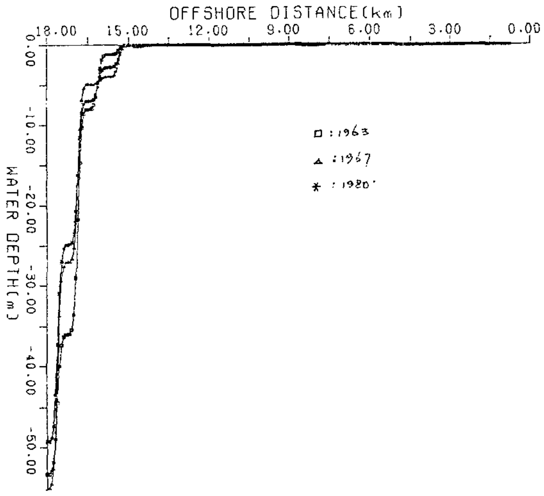

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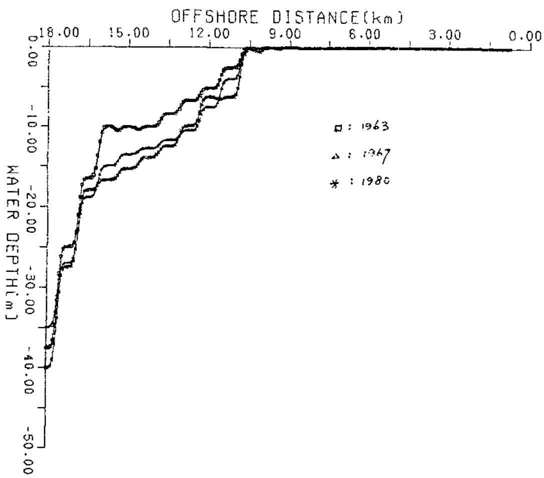

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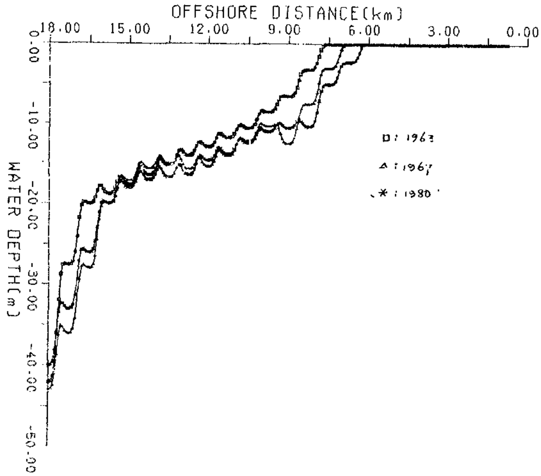

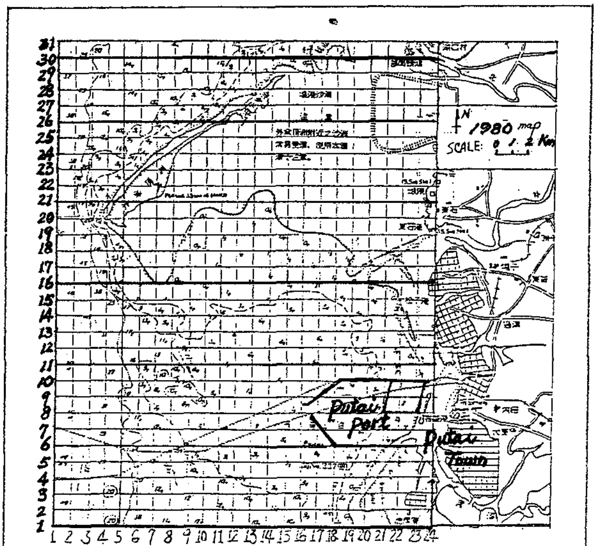

Fig. 4.8. Topography of Putai Harbor Area