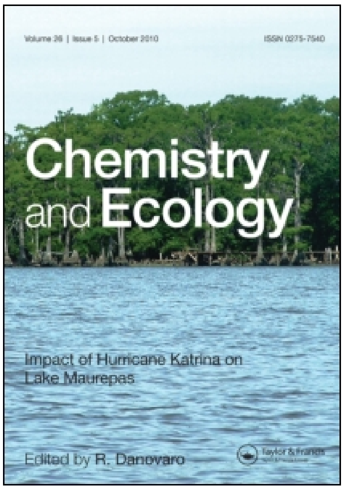

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

Study On the Hydraulic Characteristics of Taichung Harbour in Taiwan

Z. M. Tseng[a]; H. T. Chou[b]; J. T. Juang[a]
[a] Institute of Harbour and Marine Technology, Taichung, Taiwan [b] Department of Civil Engineering, National Central University, Chung-Li, Taiwan

To cite this Article Tseng, Z. M. , Chou, H. T. and Juang, J. T.(1998) 'Study On the Hydraulic Characteristics of Taichung Harbour in Taiwan', Chemistry and Ecology, 15: 1, 211 — 222
To link to this Article: DOI: 10.1080/02757549808037631
URL: http://dx.doi.org/10.1080/02757549808037631

Chemistry and Ecology, 1998, Vol. 15, pp. 211–222
Reprints available directly from the publisher
Photocopying permitted by license only

STUDY ON THE HYDRAULIC CHARACTERISTICS OF TAICHUNG HARBOUR IN TAIWAN

Z. M. TSENG[a,*], H. T. CHOU[b] and J. T. JUANG[a]

[a] *Institute of Harbour and Marine Technology, Taichung 435, Taiwan;*
[b] *Department of Civil Engineering, National Central University, Chung-Li 320, Taiwan*

(Received 18 November 1997; In final form 6 January 1998)

For this study, field measurements of current profiles, buoy trajectories and the lag of two tidal stations were performed to explore the flow characteristics of Taichung Harbour. In order to distinguish the effects of wind drift current on circulation inside Taichung Harbour, field surveys during both summer and monsoon (winter) season were completed separately. The speed of the drift current was about 3.5% that of the wind speed, based on the field data. The horizontal dispersion coefficients were close to Bowden's (1965) formula for the tidal current. The water temperature showed a two-layer profile, with the mixing thickness about 4 to 6 metres for the upper layer. The corresponding Richardson number was about 70. The tidal lag between the two tidal stations was 9.68 minutes. All the results agree well with the theoretical results.

Keywords: Dispersion coefficient; tidal lag; drogue tracking

1. INTRODUCTION

Taichung Harbour is located in the middle-western part of the Taiwan Strait (Fig. 1). From the beginning of its business operations, an important role was played for its loading and unloading capacity, shared by the two major harbours in Taiwan, Keelung Harbour in the north and Kaoshung Harbour in the south. However, water quality deteriorated due to severe influence of domestic and industrial waste. The water quality of some specific dead zones in the harbour, such as

*Corresponding author.

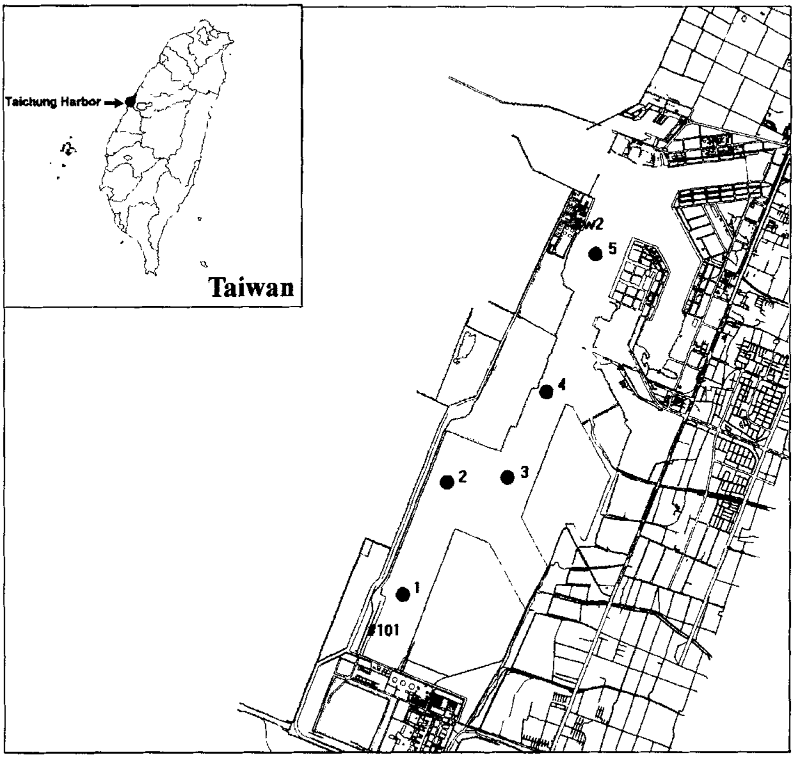

FIGURE 1 Sampling locations in the Taichung Harbour basin.

the south slip, even becomes worse due to its poor dispersion capability as well as the low dispersion of the sea water. The operation of the Taichung Power Plant at the southern end of the harbour has made the pollution even more difficult than before.

The basin of Taichung Harbour is belt-like in shape, $7 \sim 8$ km in length and 0.5 km in width. In particular, the main direction of the basin coincides with the prevailing wind direction during the winter monsoon season, when the gust speeds even become $10 \sim 20\,\mathrm{m\,s^{-1}}$. On the other hand, the mean high tidal range is about 4.6 m. In such circumstances, the influence of the drift current and the tidal circulation on pollutant flushing is worthy of more study.

A field study of the hydraulic parameters of Taichung Harbour is reported for this paper. The results are compared with a theoretical analysis and the parameters can be utilized as the input data for further numerical model simulations.

2. ESTIMATION OF THE DISPERSION COEFFICIENTS

The dispersion coefficient for the harbour basin is the most important index for the efficiency of water dilution. When the value of the dispersion coefficient is greater, the water bodies have better dilution efficiency and vice versa. The value of the dispersion coefficient is a function of flow field and is not an unique constant. Several formulae for the estimation of the dispersion coefficients are available and are used in this paper for comparison (Bowden, 1965; Csanady, 1963; Chieh, 1987; Fischer *et al.*, 1979).

The estimation of the dispersion coefficients for Taichung Harbour is based on the following background conditions:

Length: 8000 m — Width: 500 m
Water depth: 13 m — Mean high tidal range: 4.6 m
Tidal excursion: 2830 m
Mean tidal velocity $\overline{U} = 2830\,\mathrm{m}\ 6.25\,\mathrm{hr}^{-1} = 0.13\,\mathrm{m\,s}^{-1}$
Rate of transverse mixing (assumption) $U^* = 0.1\,\overline{U} = 0.013\,\mathrm{m\,s}^{-1}$

One can substitute these parameters into the available equations and obtain the following results:

3. FIELD STUDY

In order to study the hydraulic characteristics and the dispersion phenomenon of the Taichung Harbour basin as influenced by the tide and the wind force, a series of field studies for the velocity, salinity and temperature profile measurement, drogue tracking and tidal lag

TABLE I The estimated value of the horizontal dispersion coefficients in $m^2 sec^{-1}$

	Bowden, 1965	Csanady, 1963	Chieh, 1987	Fischer *et al.*, 1979
Tidal Current	0.44 ~ 1.06	0.997	1.8	0.61
Drift Current	19.2 ~ 30.0	1.46	~	~

observations at specific sites within the harbour basin during different tidal phases, such as the flood or ebb tide and during different seasons, such as the monsoon or non-monsoon season, were done. The first was on February 27, 1996, the second on March 30, 1996 and the third on the June 8, 1996.

Velocity Profile Measurement

Both an electromagnetic current meter UCM-40 and a rotary current meter RCM-7 are employed to measure the velocity profile in the harbour. A 1 m interval velocity-profile measurement was obtained from the water surface down to the bottom, based on two-minute averaged data. Simultaneously, a working boat was anchored and the location is recorded by GPS. During a round trip between the outer and the inner tips of the main channel, corresponding velocity, salinity and temperature profile data from 5 stations (refer to Fig. 1) were taken.

The measured horizontal velocity at the different water depths can be decomposed into two components, namely, the along-channel component, V_x and the cross-channel component, V_y.

$$V_x = V\cos\beta \quad \text{and} \quad V_y = V\sin\beta. \tag{1}$$

where β denotes the angle between the velocity vector and the main channel direction.

Drogue Tracking

The drogues used in this field study included three components; the upper part was a steel tube with a triangular flag; the lower part was a crossed iron plate served as a stable weight while between was a plastic buoy with a diameter of 30 cm. At two different tidal phases such as the flood tide and the ebb tide, two or three drogues would be released each time. The position coordinates of drogue j at time i are defined by (X_{ij}, Y_{ij}). From these coordinates, the Lagrangian velocity of the drogues can be computed. The centroid of N drogues at time t is given by (List *et al.*, 1990):

$$\bar{X}_i = \frac{\sum_j X_{ij}}{N}\,;\; \bar{Y}_i = \frac{\sum_j Y_{ij}}{N}. \tag{2}$$

The mean velocity of the drogue set is simply the time derivative of the co-ordinate position. The variance in the drogue position, defined by $\sigma^2_{x_i}$ and $\sigma^2_{y_i}$, is given by:

$$\sigma^2_{x_i} = \frac{\sum_j (X_{ij} - \bar{X}_j)^2}{(N-1)} \tag{3}$$

$$\sigma^2_{y_i} = \frac{\sum_j (Y_{ij} - \bar{Y}_j)^2}{(N-1)} \tag{4}$$

Following Okubo's (1974) algorithm, the dispersion of the drogues can be defined as

$$\sigma^2_i = \frac{(\sigma^2_{x_i} + \sigma^2_{y_i})}{2}, \tag{5}$$

and the relative dispersion coefficient K is given by

$$K(t_i) = \frac{1}{2}\frac{\partial \sigma^2_i}{\partial t} \approx \frac{1}{2}\frac{\Delta \sigma^2_I}{\Delta t}. \tag{6}$$

The spatially dependent relative dispersion coefficients are given by:

$$K_x(t_i) = \frac{1}{2}\frac{\partial \sigma^2_{x_i}}{\partial t} \approx \frac{1}{2}\frac{\Delta \sigma^2_{x_i}}{\Delta t} \tag{7}$$

$$K_y(t_i) = \frac{1}{2}\frac{\partial \sigma^2_{y_i}}{\partial t} \approx \frac{1}{2}\frac{\Delta \sigma^2_{y_i}}{\Delta t}. \tag{8}$$

Tidal Lag Observation

For the purpose of distinguishing the influence induced by the tidal variations from those of wind drift within the harbour basin, we set up two tidal gauges: one on the pier (west #2) near the harbour entrance and the other on Tai-power pier (#101 Coal Unloading Wharf) located on the inner-south tip of the main channel. According to the shallow-water wave theory, the tidal lag between the two gauges, with distance L and water depth h is

$$t_1 = L\,(gh)^{0.5} \tag{9}$$

4. DATA ANALYSIS

Current Velocity Profile

The sampling stations for the second field study on March 30, 1996 are shown in Figure 1. At Station 1, the velocity profile was rather irregular in the morning and have an obviously wind drift trend in the afternoon. As shown in Figure 2, its surface velocity is about $0.30\,\mathrm{m\,s^{-1}}$ with a return flow occurs at a depth of $-7\,\mathrm{m}$. In Figure 3, the velocity profile at Station 3 had an obvious wind drift trend in the afternoon as well and its surface velocity was about $0.25\,\mathrm{m\,s^{-1}}$ with a return flow occuring at $-4\,\mathrm{m}$. The velocity profiles at the other three stations were rather irregular.

During the third field study on June 8, 1996, the averaged transverse tidal velocities of Stations 1 to 5 were about $0.1\,\mathrm{m\,s^{-1}}$, $0.15\,\mathrm{m\,s^{-1}}$, $0.15\,\mathrm{m\,s^{-1}}$, $0.22\,\mathrm{m\,s^{-1}}$ and $0.17\,\mathrm{m\,s^{-1}}$ in the morning and $0.08\,\mathrm{m\,s^{-1}}$,

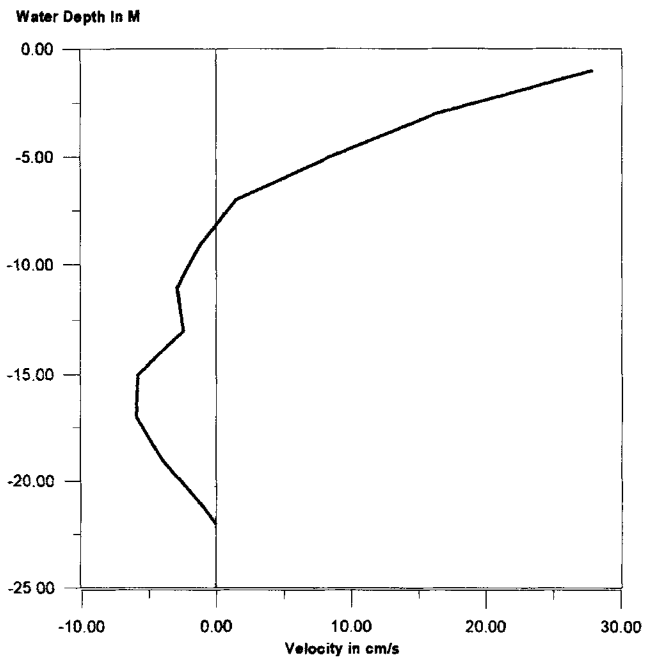

FIGURE 2 Velocity profile of the Taichung Harbour basin (Station 1 along the channel '96-03-30 Afternoon).

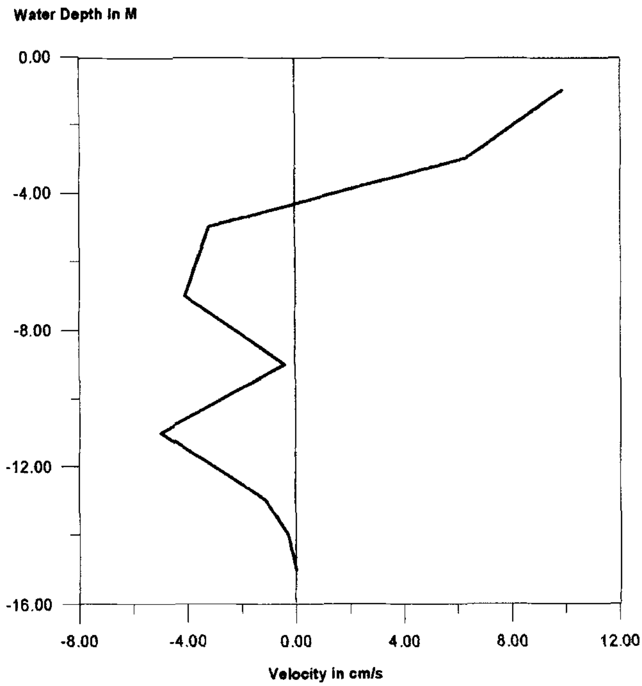

FIGURE 3 Velocity profile of the Taichung Harbour basin (Station 3 cross the channel '96-03-30 Afternoon).

$0.12\,\mathrm{m\,s^{-1}}$, $0.13\,\mathrm{m\,s^{-1}}$, $0.20\,\mathrm{m\,s^{-1}}$ and $0.17\,\mathrm{m\,s^{-1}}$, in the afternoon. According to the data, the tidal flow was mainly longitudinal to the main channel. However, the transverse components were non-negligible.

Drogue Tracking

Based on the results of drogue tracking during the second field study on March 30, 1996 and the third field study on June 8, 1996, the trajectories of the drogues coincide with the direction of the wind drift, that is from NNE to SSW with an average velocity of $0.20\,\mathrm{m\,s^{-1}}$. According to the previous analysis (List *et al.*, 1990), the calculated horizontal dispersion coefficients in the morning were $0.517\,\mathrm{m^2\,s^{-1}}(K_x)$ and $0.152\,\mathrm{m^2\,s^{-1}}(K_y)$, respectively; and the values read $1.69\,\mathrm{m^2\,s^{-1}}(K_x)$ and $0.134\,\mathrm{m^2\,s^{-1}}(K_y)$ in the afternoon. The inferred surface velocity was about $25 \sim 35\,\mathrm{cm\,s^{-1}}$, which agrees quite well with the field velocity profile observation. In other words, it was about 3.5% of the average wind velocity at that time.

Tidal Lag Observation

The tidal elevation curves for the two tidal gauges during the first and the third field studies are shown in Figures 4 and 5. Based on data from two tidal gauges in the second field study on March 30, 1996 (refer to Fig. 4), the observed ebb-tide lag was 9 minutes and 42 seconds, quite close to 9 minutes and 32 seconds, calculated according to Eq. (1) (the water depth was 12 m and the distance between the two tide-gauges 6.2 km). Meanwhile, the tidal range at the inner side of main channel was slightly smaller than the value at the outer station.

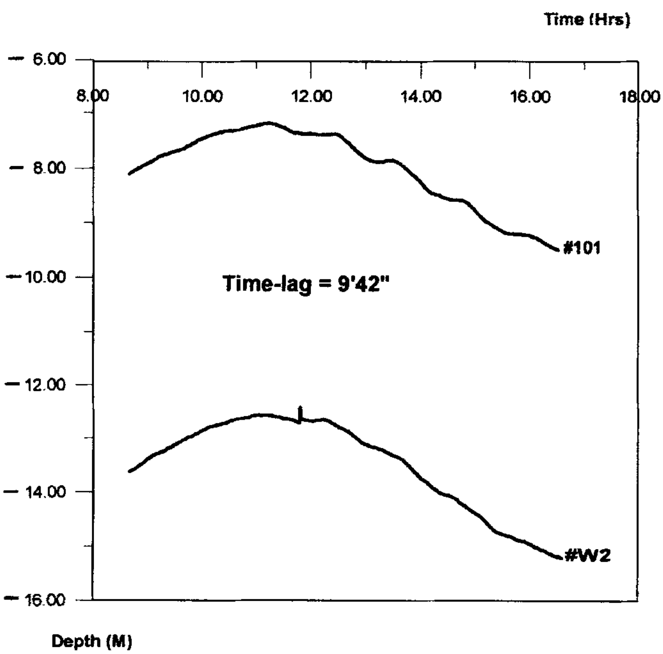

FIGURE 4 Tide-change in Wharf #W2 and #101 ('96-02-07, Time-lag 9'42").

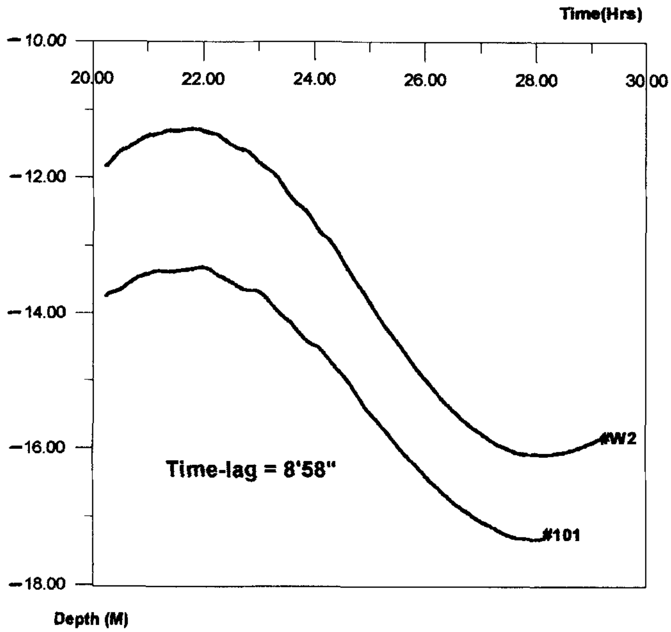

FIGURE 5 Tide-change in Wharf #W2 and #101 ('96-06-08, Time-lag 8'58").

Temperature Profile

From the observed temperature profiles as shown in Figures 6 and 7, there is little temperature stratification at each site, except Station 1, near the inlet of the Tai-Power Plant. Due to the withdrawal of cooling water, the flow pattern is more complicated in stratification than at the other stations. Usually there exists a two-layered temperature profile, with the upper mixed layer about 4 ~ 6 m in thickness, with the lower unmixed layer having a temperature difference at about 0.6°C in the morning and 1.2°C in the afternoon.

Salinity Profile

The salinity profiles for Stations 2 and 4 during the third field study are shown in Figures 8 and 9. The salinity profiles show a tendency to increase with the water depth. Due to the inflow of fresh water from a nearby sewer aqueduct (refer to Fig. 1), the salinity near the water surface at these two stations is lower than at the other sites.

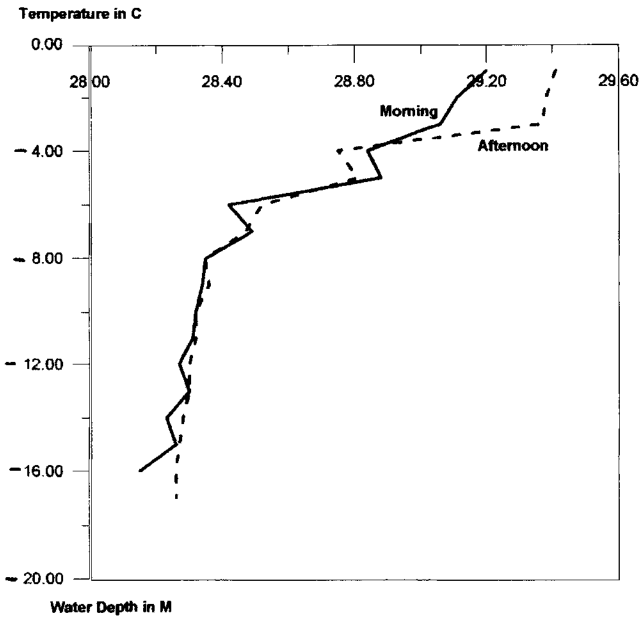

FIGURE 6 Temperature profile of the Taichung Harbour basin (Station 2 '96-06-08).

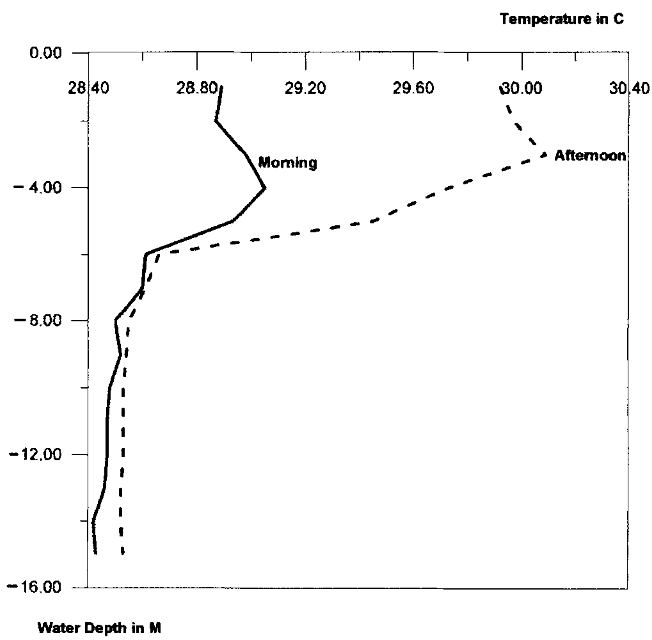

FIGURE 7 Temperature profile of the Taichung Harbour basin (Station 4 '96-06-08).

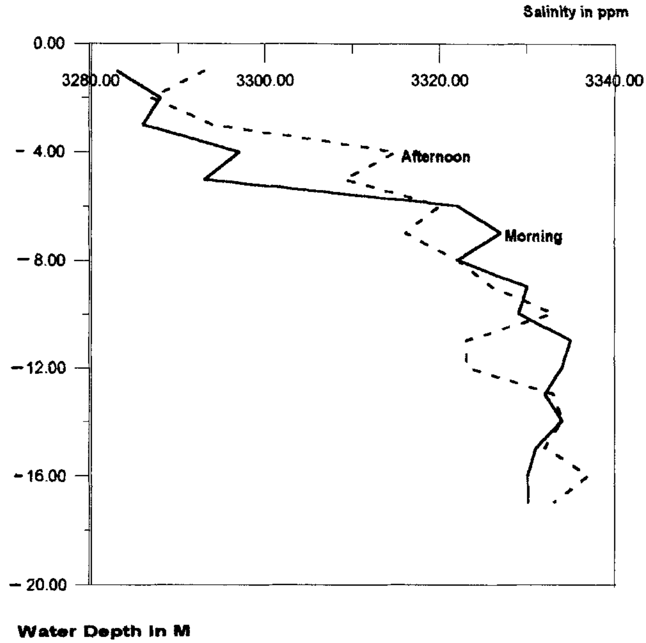

FIGURE 8 Salinity profile of the Taichung Harbour basin (Station 2 '96-06-08).

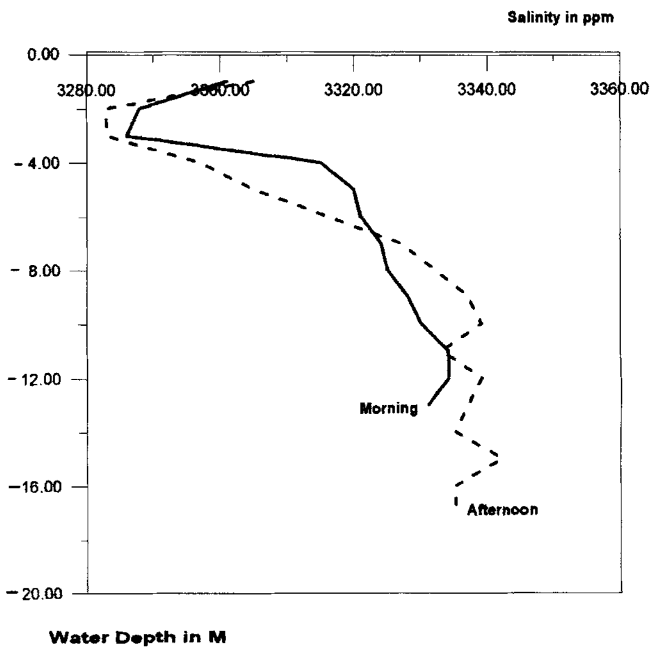

FIGURE 9 Salinity profile of the Taichung Harbour basin (Station 3 '96-06-08).

5. CONCLUSIONS

(1) A comparison of the dispersion coefficients according to drogue tracking, with the available formulae, both agree quite well. The order of the dispersion coefficients is about $1\,m^2\,s^{-1}$. The inferred surface velocity is about $25 \sim 35\,cm\,s^{-1}$, which agrees quite well with the field velocity profile observation. In other words, it is about 3.5% of the average wind velocity at that time.

(2) Based on tidal gauge data from the second field study on March 30, 1996, the observed ebb-tidal lag is 9 minutes and 42 seconds, quite close to 9 minutes and 32 seconds, which is calculated based on the shallow-water wave theory.

(3) There was little temperature stratification, with a two-layered temperature profile, at most of the observed sites. The upper mixed layer was about $4 \sim 6\,m$ in thickness and the lower unmixed layer has a temperature difference with respect to an upper layer of about 0.6°C in the morning and 1.2°C in the afternoon.

(4) The salinity profiles for the Taichung Harbour basin show a tendency to increase with the water depth. Owing to the inflow of fresh water from a nearby sewer aqueduct, the salinity near the water surface at Stations 2 and 4 is lower than at the other sites.

References

Bowden, K. F. (1965) Horizontal mixing in the sea due to a shearing current, *J. Fluid Mech.*, **21**, 83–95.

Chieh, S. H. (1987) Two-dimensional model of thermal discharges in coastal regions. *J. Hydraulic Engrg., ASCE*, **113**, 1032–1040.

Csanady, G. T. (1963) Turbulent diffusion in Lake Huron. *J. Fluid Mech.*, **17**, 360–384.

Fischer, H., List, E. J., Koh, B. C. Y., Imberger, J. and Brooks, N. (1979) *Mixing in Inland and Coastal Waters*, Academic Press, New York.

List, E. J., Gartrell, G. and Winant, C. D. (1990) Diffusion and dispersion in coastal waters, *J. Hydraulic Engrg., ASCE*, **116**, 1158–1179.

Okubo, A. (1974) Some speculations on oceanic diffusion diagrams, *Rapp. P.-v. Reun. Cons. Int. Explor. Mer.*, **167**, 77–85.