CHAPTER 2

TIDAL MOTION AND NUMERICAL MODEL

2.0 INTRODUCTION

For the past three centuries the phenomenon of tide has drawn considerable attention of numerous scientists such as Newton, Laplace, Airy, Darwin, Thomson, Doodson, Lamb and Proudman. As a consequence, tidal phenomena have been one of the most studied areas in physical oceanography. The tide generating forces originate from the gravitational attractions of the Sun and the Moon on the water bodies of the Earth; and the relative motion of the Earth and the Moon revolving around the Sun with different period causes the occurrence of different harmonic components of tides. Due to the relatively smaller water mass, the tidal motions in the straits or a semi-enclosed coastal sea are generally controlled by the ocean tide entering through an opening or shelf area of the surrounding sea. Theory on equilibrium tide and tidal current could be found in Dietrich et al., 1980, Dronkers, 1964, and Pond and Pickard, 1990. A brief description on the nature of tidal processes would be discussed and important aspects in the numerical computation are given below as useful background information.

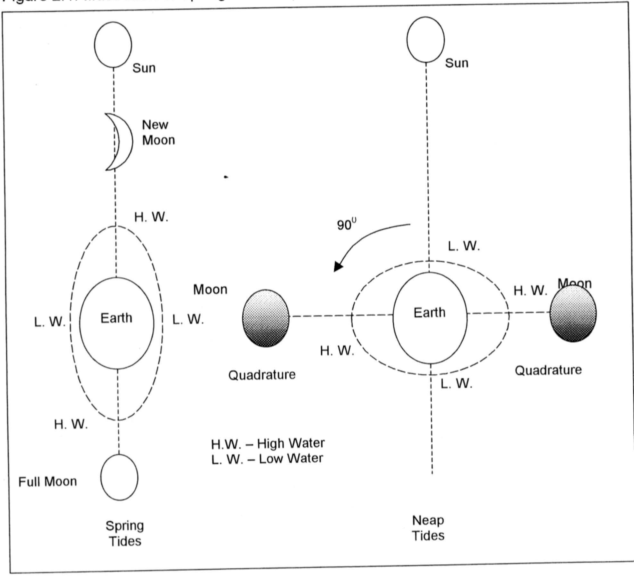
2.1 TIDES AND TIDAL FORCING

The rhythmic rise and fall of sea level along the world's coastlines are the most apparent manifestation of tides. In some coastal locations, tides are noticeable but not spectacular, but in other places, the tides are spectacularly large. In some places, the sea level rises and falls with a period of about half a day (these are called semidiurnal tides), whereas in other places the period is more like a day (called diurnal tides). In some locations the tides are mixtures of semidiurnal and diurnal types. There are periods during the year when the Sun and Moon line up on the same side with the Earth, producing tides which are unusually large called spring tides. This occurs a few days after both new and full moon. Whereas, when the Sun and the Moon are at quadrature position with the Earth, the minimum ranges called neap tides are produced and occur shortly after the times of the first quarters (lunar quardrature). Figure 2.1 shows the features of spring and neap tides.

Generally, there are two types of tides: diurnal and semidiurnal components. The more commonly encountered semidiurnal tide is one in which two high waters and two low waters occur each day, the times of high water and low water becoming later by approximately 50 minutes from one day to the next. Previous investigations showed that the Straits of Malacca is mainly dominated by the lunar semidiurnal constituent, denoted by M2, in which each tidal cycle takes an average of 12.42 hours. Semidiurnal tides have a range that typically increases and decreases cyclically over a fourteen days period.

While the rhythmic modulation of the sea level and its association with the motion of the Sun and the Moon must have been noticed since pre-historic times, a better understanding was only obtained when Sir Isaac Newton applied his theory of gravitation to explain the underlying physical mechanism. He was able to construct an equilibrium theory of tides, which explained the semidiurnal nature of tides in most parts of the world. If there were infinite time allowed for adjustment of the ocean to the astronomical forces, it is equilibrium tides that would result. This is however not the case since tidal forcing varies quite rapidly with time. Resonance in the oceanic response pushes tides in certain localities to be above the values predicted by equilibrium theory. While the equilibrium theory predicts two bulges to form, one underneath the Moon and the other on the opposite side of the Earth, in reality the high water may significantly precede or lag the transit of the Moon. These differences are due to the dynamical response of the oceans to tidal forcing. It was Laplace who, a century later, laid the theoretical and mathematical foundations for a modern dynamical theory of ocean tides by considering oceanic tides to be the response of the fluid medium to the astronomical forcing by the Sun's and Moon's gravitational attractions. In this approach, the tides result from the dynamical balances principally between the tractive forces due to gravitation and retarding forces due to friction in the water column.

Figure 2.1: Illustration of Spring and Neap tides



2.2 TIDAL CONSTITUENTS

While the rise and fall of the sea level is the most apparent aspect of tides, it is tidal currents that are the direct manifestation of tides, and the sea level rise and fall is due to the resulting convergence and divergence of the water masses. The Sun and the Moon are the only important celestial bodies in producing terrestrial tides. While the Moon is much smaller than the Sun, it is nevertheless more important for tidal processes because of its proximity to the Earth. It is the small imbalance between the centrifugal force and gravitational attraction of the Moon on the water column that gives rise to horizontal tractive forces, causing water motion that tends to form two bulges in the sea surface, one immediately underneath and the other on the other side of the globe. These bulges tend to rotate around the globe along with the Moon resulting in semidiurnal tides with a period of half a lunar day (12.4 hour), even though the Earth's rotation is diurnal (period of 24 hours). To model tidal motion, it is in theory necessary to prescribe the astronomical forcing. However, for marginal seas open to primary oceans, this astronomical forcing could be neglected and it is sufficient to prescribe the tidal forcing on the imaginary boundaries open to the oceans. The Straits of Malacca is such an example; the tides here co-oscillate with tides entering the Straits from the Andaman Sea and South China Sea. This force is more dominant than the astronomical forcing which is negligible by comparison.

The tidal potential solution from equilibrium theory could be expressed as a Fourier series, with each term representing a tidal constituent. While there are tens of such constituents in general expansion, usually only the so-called primary components are important. Table 2.1 gives the period and description of each of these constituents. Except in some isolated situations where other constituents become important, it is seldom necessary to include many components to obtain accurate tidal predictions. Previous investigations by Lee,1994, Mihardja and

Radjawane, 1992, and Hadi, 1992 in the Straits of Malacca had shown that it is sufficient to include the two semi-diurnal components, M2 and S2 and two diurnal components K1 and O1 to obtain accurate tidal prediction.

Table 2.1: Primary Tidal Components.

Tidal Component	Period (solar hours)	Description	Nature
M2	12.42	Principal lunar	Semidiurnal
S2	12.00	Principal solar	Semidiurnal
N2	12.66	Larger lunar elliptic	Semidiurnal
K2	11.97	Luni-solar	Semidiurnal
K1	23.93	Luni-solar diurnal	Diurnal
O1	25.82	Principal lunar diurnal	Diurnal
P1	24.07	Principal solar diurnal	Diurnal
Q1	26.87	Larger lunar elliptic	Diurnal
MF	327.90	Lunar fortnightly	Long term
MM	661.30	Lunar monthly	Long term
SSA	4383.00	Solar semidiurnal	Long term
M4	6.21		Compound
MS4	6.10		Compound

A general approach to tidal prediction is to gather observations over a long period and use the time series to extract the various constituents by harmonic analysis. This method works only for places where observations are available, such as coastal stations and a few offshore stations in the sea. However, for the majority of the seas and interior of basins, there exist no observations and it is therefore necessary to resort to numerical models.

2.3 NUMERICAL MODELLING OF TIDAL MOTION

Two-dimensional vertically integrated hydrodynamic models are well established and have been used in a large number of oceanic problems, such as from global scale tidal modelling, shelf circulation problems and storm surge in shallow seas. The early works in numerical modelling of tides have been based on this approach and employ the vertically integrated continuity and momentum equations to predict the surface elevation and depth-averaged velocity components. If time dependent, the model is initiated from a state of rest and integrated in time until the associated transients have been damped out.

Review of much of the work on two-dimensional numerical tidal models are given by Liu and Leendertse, 1978. While these two-dimensional models, to a certain extent, have been superseded by full three-dimensional models in recent years, they remain of considerable usefulness for tidal flow where the fluid velocity is not strongly dependent on the vertical coordinate, i.e. not strongly affected by gradient density and the surface wind. Furthermore, the application of a three-dimensional model requires extensive computation on a large number of grid points if good resolution is needed. Therefore, two-dimensional models are still preferred for algorithms designed for small computers.

A major problem confronting the numerical modeller of tidal motion in the Straits of Malacca is the reconciliation of model results with observed data. Typically, the observed data is seriously inadequate. Time series of sea level elevations are available along the coastline at a number of isolated tidal stations.

At open boundaries across the water mass the situation is worse. Hardly any data is available and the form of the boundary condition is very uncertain. Though the elevation information at the coast is relatively certain by comparison, it is unfortunate that a numerical scheme with finite grids often requires a choice to be made between the sea level data and the impervious boundary condition at the coast. As a result, one is forced to abandon either the impervious boundary condition or the sea level data on the coastline, and take the lesser known condition on the open boundary.

Therefore, it is the aim of this thesis to study the sensitivity of the model output on the prescription of tidal elevations at the open boundaries. However, assigning of conditions at open boundaries (such as at the openings of the Straits) must be done with cautions. It is necessary to preserve and specify, either from observations and/or by estimates, features that enter the domain, and also to allow features to exit without generating disturbances inside the modelled region.

2.4 A BRIEF REVIEW ON TIDAL STUDY AND MODELLING IN THE STRAITS OF MALACCA.

There has been very few publications on tidal study and modelling in the region of the Straits of Malacca. Nevertheless, a few regional and local studies had been carried out in the Malaysian as well as the Indonesian waters and the surrounding areas in South East Asia. The studies so far provided a general understanding on the tidal motion and characteristics of tides in the Straits of

Malacca. The results of the regional and local studies that have been done are discussed briefly in the following section.

2.4.1 REGIONAL STUDIES BY WYRTKI, 1961.

Wyrtki, 1961 carried out some investigations in the Southeast Asian waters. He had given a general description on the geographical distribution of the tidal types in the Southeast Asia waters based on the division proposed by Dietrich, 1944.

His results showed that the northwestern part of the Straits of Malacca was dominated by pure semidiurnal tides. The semidiurnal tidal wave entered from the Andaman Sea and advanced slowly through the Straits of Malacca. Due to the contraction of the Straits, the amplitudes rose from 80 cm at the entrance to more than 250 cm in the narrowest part off Melaka. Later the amplitude decreased again and the rest of the wave passed over into the South China Sea. At the southeasthern part near Singapore the tidal pattern was mixed, predominantly semidiurnal tides, which was due to the effect of penetration of the diurnal wave from the South China Sea and Java Sea into this region.

2.4.2 TIDAL PHENOMENA IN ASEAN WATERS BY GUOY, T.K.,1989

Guoy, 1989, analysed the tidal characteristics of the ASEAN region by using the sea level data and regional distribution of harmonic constants. He applied the simplified equations of momentum and continuity to study the hydrodynamics of a selected area in the Straits of Malacca. The M2 and K1 components were selected as representatives of the typical semidiurnal and diurnal tides respectively. Generally, the model results showed a good fit with the actual observation data except in isolated cases. The overall conclusion was that the entire Straits of Malacca was dominated by semidiurnal tides, while the southern part was mixed but still predominantly semidiurnal in nature. Guoy also attempted an analysis of the effect of frictional coefficient on the model results. Though the results were not conclusive, it provided a little insight into the nature of this coefficient.

2.4.3 NUMERICAL TIDAL MODEL BY MIHARDJA, D.K. AND RADJAWANE, I.M., 1992

Mihardja and Radjawane, 1992, had used a numerical method to investigate the behaviours of the four tidal constituents (M2, S2, K1 and O1) in the Straits of Malacca. The two-dimensional transient hydrodynamic model was simulated numerically by using a two-step semi-implicit method. The grid was set up by rotating through 45^0 with respect to the geographical grid system to match the coastline more closely. This produced grid sizes of 10.0'(x = 18333 m) in the northwest-southeast direction and 3.33' (y = 6111 m) in the northeast-southwest direction, giving a total of 69 X 82 grid cells.

The amplitude and phase difference results from the simulation generally showed good agreement with the Monaco data, especially for the diurnal components. The results also confirmed that the Straits of Malacca was dominated by semidiurnal tides from the Andaman Sea and Northern Indian Ocean. The Singapore Straits had a mixed pattern, predominantly semidiurnal, due to the influence from the diurnal tides originated from the South China Sea and Karimata Straits. It was argued that the semidiurnal tidal wave was dominant in the Malacca Straits because the natural period of the Straits was close to the period of semidiurnal M2.

2.4.4 HYDRODYNAMICS MODEL BY HADI, S., 1992.

Hadi, 1992 had incorporated the contribution of wind stress in the vertically integrated shallow-sea hydrodynamics model. The model was simulated for three prevailing winds, i.e: Northeast, Northwest and South winds. His results showed that the seasonal monsoons did not have any effect on the current patterns as the flow in the Malacca Straits was mainly determined by the tidal behaviours of the Andaman Sea and South China Sea.

2.4.5 TIDAL MODELLING BY LEE, G.P.,1994.

Lee, 1994 developed a tidal sub-model to be included in an oil spill model. A one-dimensional model, where the Straits of Malacca was divided into 74 sections, was used to model the main tidal components of M2, S2, K1 and O1 along the centreline. A two-dimensional time-independent model using 150 X 72 grid cells ($\Delta x = \Delta y = 3.5'$) had been attempted too. The grid system was set up by rotating 45^0 with respect to the geographical grid system as adopted by Mihardja and Radjawane, 1992.

The results of these two models showed overall good agreement with the observed tidal amplitudes and phases in the mid-channel, especially in the southern part of the Straits. Generally, the two-dimensional model did not give accurate prediction for the tidal components near the coast as well as in the areas around islands.