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Clockwise Phase Propagation of Semi-Diurnal Tides in the Gulf of Thailand

TETSUO YANAGI[1] and TOSHIYUKI TAKAO[2]

[1]*Research Institute for Applied Mechanics, Kyushu University, Kasuga 816, Japan*
[2]*Department of Civil and Environmental Engineering, Ehime University, Matsuyama 790, Japan*

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The phase of semi-diurnal tides (M_2 and S_2) propagates clockwise in the central part of the Gulf of Thailand, although that of the diurnal tides (K_1, O_1 and P_1) is counterclockwise. The mechanism of clockwise phase propagation of semi-diurnal tides at the Gulf of Thailand in the northern hemisphere is examined using a simple numerical model. The natural oscillation period of the whole Gulf of Thailand is near the semi-diurnal period and the direction of its phase propagation is clockwise, mainly due to the propagation direction of the large amplitude part of the incoming semi-diurnal tidal wave from the South China Sea. A simplified basin model with bottom slope and Coriolis force well reproduces the co-tidal and co-range charts of M_2 tide in the Gulf of Thailand.

Keywords:
· Clockwise amphidrome,
· natural oscillation,
· tide,
· Gulf of Thailand.

1. Introduction

It is well known that the phase of tides propagates counterclockwise (clockwise) in gulfs or shelf seas such as the North Sea, the Baltic, the Adria, the Persian Gulf, the Yellow Sea, the Sea of Okhotsk, the Gulf of Mexico and so on in the northern (southern) hemisphere and such a phenomenon is well explained by the superposition of incoming and reflecting Kelvin waves (Taylor, 1920). But the phase of semi-diurnal tides in the Black Sea propagates clockwise and Sterneck (1922) explained this remarkable phenomenon in terms of the phase lag between the east-west natural oscillation forced by the east-west component of tide-generating force and the north-south one forced by the north-south component of tide-generating force in the Black Sea, neglecting the Coriolis force. After high water along the east coast, the high water occurs along the south coast of the Black Sea because the natural oscillations in east-west and north-south directions have the phase difference of $\pi/2$. The counterclockwise phase propagation of diurnal tides (K_1 and O_1) in the Black Sea is also explained by the same theory (Sterneck, 1922).

The phase of diurnal tides (K_1, O_1 and P_1) propagates counterclockwise at the central part of the Gulf of Thailand in the northern hemisphere, as shown in Fig. 1(b) but that of semi-diurnal tides (M_2 and S_2) propagates clockwise there as shown in Fig. 1(a) (Yanagi *et al.*, 1997).The observed directions of the phase propagation of diurnal and semi-diurnal tides are well reproduced by numerical experiments (Yanagi and Takao, 1997).

In this paper we reveal the mechanism of the clockwise phase propagation of semi-diurnal tides at the Gulf of Thailand in the northern hemisphere using a simple numerical model.

2. Gulf of Thailand

The Gulf of Thailand is situated in the southwestern part of the South China Sea and the length from the shelf edge to the head of the gulf, L, is about 1,500 km; its width, B, is about 460 km and its average depth, H, is about 40 m (Fig. 2). Because the phase speed of the long wave in the gulf $C = \sqrt{gH}$ is about 20 m s^{-1}, the wavelength of the semi-diurnal tidal wave $l_{M_2} = CT_{M_2}$ (T_{M_2} is the semi-diurnal period) is 890 km and that of diurnal one l_{K_1} is about 1,700 km. These are nearly one half of and the same as the length of the gulf L, respectively. The inertia period T_i ($=2\pi/f$, f; the Coriolis parameter $= 2\omega\sin\phi$, ω; the angular velocity of the earth's rotation, ϕ; the latitude = 9°N in this case) of the gulf is 76.6 hours. The Rossby deformation length λ ($=\sqrt{gH}/f$) of the gulf is 870 km.

Semi-diurnal and diurnal tidal periods are much shorter than the inertia period and the width of the gulf is narrower than the Rossby deformation length in the Gulf of Thailand. These facts suggest that the tidal phenomena are not seriously affected by the Coriolis force in the Gulf of Thailand.

3. Numerical Model

The horizontal two-dimensional momentum and continuity equations for tide and tidal current of a homogeneous fluid under Cartesian coordinates are as follows;