ANZIAM J. 46 (E) pp.C888–C901, 2005

Modelling the effect of proposed channel deepening on the tides in Port Phillip Bay

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(Received 8 October 2004, revised 15 August 2005)

Abstract

The Victorian State Government is investigating a proposal to deepen the channels into Port Phillip Bay in order to bring larger ships into the Bay. The Port of Melbourne Corporation, the Victorian State Government authority responsible for the channel deepening, concluded that the largest increase in tidal height due to the channel deepening will be eight mm. We independently study the effect of the channel deepening on the astronomical tides. The levels of

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See http://anziamj.austms.org.au/V46/CTAC2004/Samp for this article, © Austral. Mathematical Soc. 2005. Published September 6, 2005. ISSN 1446-8735

tides for the existing topography and for the topography including the proposed channel deepening have been computed. Our results show that the effect of channel deepening on the astronomical tides will be to increase the maximum tidal height at most locations. We calculate that the largest increase will be seven mm, confirming the results of the Port of Melbourne Corporation.

Contents

1 Introduction

Currently, the maximum draft in the main commercial shipping channels of Port Phillip Bay, Victoria, Australia, is 11.6 metres at all tides. The government of Victoria has plans to deepen the channels in Port Phillip Bay so that they can accommodate ships of up to 14 metres draft at all tides. This involves deepening sections of the Great Ship Channel at the Bay's entrance, the South Channel, and channels going into Port Melbourne and Williamstown. In July 2004 the Port of Melbourne Corporation, the Victorian State government authority responsible for the channel deepening project, released the Environmental Effects Statement on the channel deepening project. The Victorian Government appointed an independent panel to hold an enquiry on the Environmental Effects Statement on the channel deepening project in Port Phillip Bay beginning August 2004. Interested parties were invited to make a written submission to the panel. We made a submission on that section of the Environmental Effects Statement dealing with the effect of the channel deepening on the astronomical tides, the periodic rise and fall of the sea due to the gravitational attraction of the Moon and Sun. This section of the Environmental Effects Statement was written by Lawson and Treloar [5, 6].

Lawson and Treloar modelled the astronomical tides in Phillip Bay. The levels of tides for the existing topography and for the topography including the proposed channel deepening were computed. Their results show that the effect of the proposed channel deepening on astronomical tidal levels in Port Phillip Bay will be to increase the maximum tidal height at most locations, with the greatest increase eight mm and the greatest reduction two mm.

Our model gives results very close to those of Lawson and Treloar, with the maximum tidal height increasing at most locations, but with a greatest increase of seven mm and a greatest reduction of two mm.

Our results at seven sites show that our model accurately models the existing tides, as does the model of Lawson and Treloar and that of Walker [9]. Our results for the post-channel deepening, predicting the largest increase in maximum tidal height of seven mm, are very close to those of Lawson and Treloar, who predict eight mm.

2 The model

In our study we have modelled the existing astronomical tides and the astronomical tides with the proposed channel deepening in Port Phillip Bay, using numerical solutions of the two-dimensional depth-averaged shallow water wave equations (see [10]). The results of this study are compared in Table 1 with the results of Lawson and Treloar [5, 6].

We used a different numerical scheme to that of Lawson and Treloar, with slightly different boundary conditions and a different mesh. Our grid contains 2618 triangular elements and 1429 nodes, with a fine grid near the entrance to the bay. Triangle sides range from 300 m in the entrance to 2–2.5 km in the North of the bay. In contrast, Lawson and Treloar used a curvilinear grid ranging in size from 30–35 m at the entrance to 300–500 m in the north. Our scheme is finite element in space and finite difference in time and explicit, whereas Lawson and Treloar's scheme is finite difference both in time and space. Our model area included all of Port Phillip Bay apart from Swan Bay and extended into Bass Strait, a region of water south of Port Phillip Bay, a distance ranging from 10 to 25 km. Lawson and Treloar's model area included all of Port Phillip Bay and extended 15 km offshore into Bass Strait. In setting up the open boundary conditions for our model we considered the open boundary conditions used by Black et al. [1], Lawson and Treloar [6] and Walker [9] in modelling tidal flow in Port Phillip Bay and Fandry, Hubbert and McIntosh [2] in Bass Strait. Because of experimental evidence that there are rapid spatial changes in tidal amplitudes in the neighbouring region Walker concluded that the Point Lonsdale sea level data was not suitable for forcing his model. Black et al. measured amplitudes and phases of tidal constituents at a point about 30 kms south of Pt. Lonsdale. They found that all components had similar values to those at Lorne, which is about 60 kms. south west of Pt. Lonsdale, with the exception of the M_2 component which was about 10% larger. All the authors quoted except Fandry et al. used modified values of the Lorne data for forcing. Walker and Black et al. used the M_2, S_2, K_1 and O_1 constituents for forcing. Lawson and Treloar used the same constituents plus N_2. We found that using similar forcing data for the same constituents gave accurate values of tidal levels at five points inside the bay but gave M_2 amplitudes about 50% larger than the observed at Queenscliff and Pt. Lonsdale. Perhaps this is because our triangles at the entrance are not small enough. Black et al. found that they obtained accurate tidal levels inside the bay but had an M_2 amplitude at Pt. Lonsdale that was 30% too large. We found that if amplitudes and phases of the constituents at Pt. Lonsdale were used for tidal forcing at the boundary in Bass Strait, then accurate results were obtained at all locations inside the bay. Then we modified the values of these amplitudes and phases to minimise the errors in the modelled data. We used five tidal constituents only as these five constituents measure about 75% of the tidal variation [7, 8], thus giving an accurate estimate of the total change that channel deepening will cause.

The two-dimensional depth-averaged shallow water wave equations [10] consist of the conservation of momentum equation in the East direction

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} - \nu\left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2}\right) + \frac{gn^2 U\sqrt{U^2+V^2}}{(h+\zeta)^{4/3}} + g\frac{\partial \zeta}{\partial x} = 0\,, \quad (1)$$

the conservation of momentum equation in the North direction

$$\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial y} - \nu\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2}\right) + \frac{gn^2 V\sqrt{U^2+V^2}}{(h+\zeta)^{4/3}} + g\frac{\partial \zeta}{\partial y} = 0\,, \quad (2)$$

and the conservation of mass equation

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (h+\zeta)U}{\partial x} + \frac{\partial (h+\zeta)V}{\partial y} = 0\,, \quad (3)$$

where $\zeta(x,y,t)$ is the height of the water surface above a horizontal datum, $z=-h(x,y)$ is the bottom surface, $U(x,y,t)$ is the depth averaged velocity component of the water current to the East, $V(x,y,t)$ is the depth averaged velocity component of the water current to the North, n is Manning's constant, ν is the horizontal eddy viscosity, g is the acceleration due to gravity and t is the time.

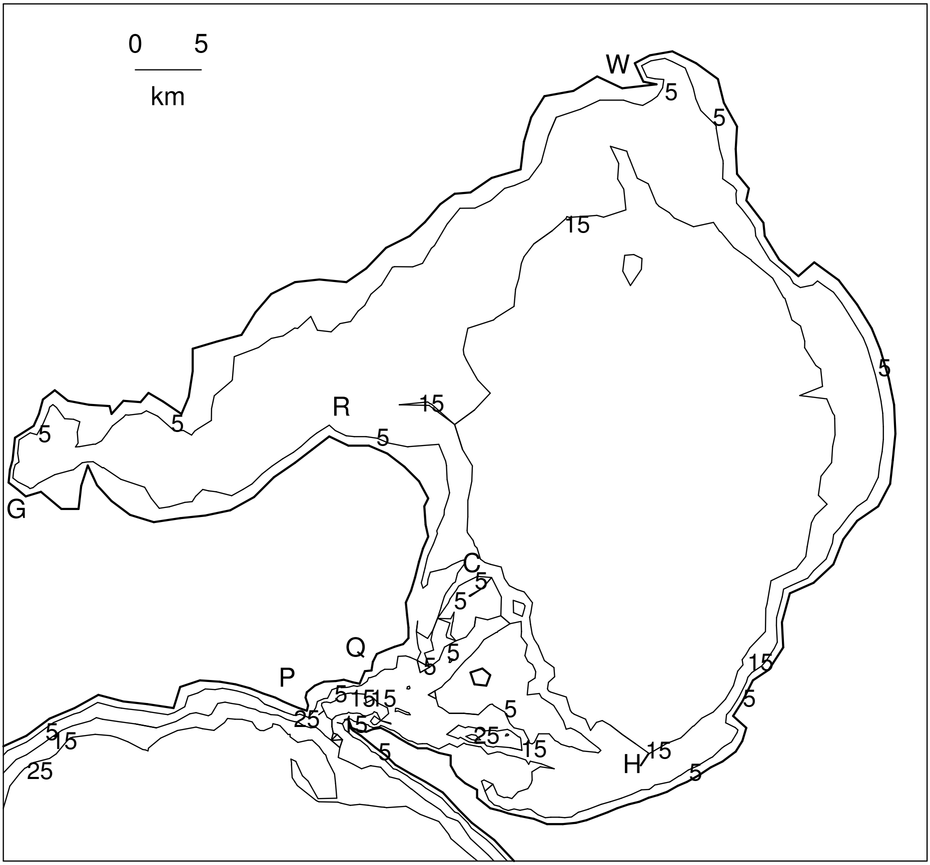

Figure 1: Depth contours (m) and locations in Port Phillip Bay. Locations are indicated by letters; P is for Pt. Lonsdale, R for Pt. Richards Channel No. 1, Q for Queenscliff, H for Hovell Pile, C for West Channel Pile, G for Geelong and W for Williamstown.

The initial conditions used in our model are $\zeta = 0$, $U = 0$, $V = 0$ at time $t = 0$. At land boundaries, the flow normal to the coastline is zero. At the sea boundary, which consists of two straight line segments,shown in the bottom left hand corner of Figure 1, the sea surface elevation, ζ_b, is specified for all time as the sum of five tidal constituents (M_2, S_2, K_1, O_1 and N_2), that is,

$$\zeta_b = \sum_{j=1}^{5} a_j \cos(\omega_j t - \gamma_j)\,, \tag{4}$$

where, for tidal constituent j, a_j is the amplitude, γ_j is the phase, and ω_j is the angular frequency.

The equations were solved numerically using the Selective Lumped Mass Scheme [4]. A computer code was written in Visual C++ to implement the scheme. The scheme solves for ζ, U and V at each time step, Δt. The scheme involves a selective lumping parameter, s_R. The Selective Lumped Scheme is restricted by the stability requirement [3],

$$\Delta t \leq d_m \Delta x / \sqrt{gh}\,, \tag{5}$$

where Δx is the smallest space step, and d_m is a function of s_R. The time step used was 13.5 seconds.

The modelled results for the amplitudes and phases of the tidal constituents at seven locations were compared with the observed results. The data for the observed amplitudes and phases of the tide are obtained from the Port of Melbourne Corporation Tables [7, 8]. The most accurate values were found when n was chosen to be $0.0195\,\mathrm{m}^{-1/3}\mathrm{s}^{-1}$ and ν to be $6\,\mathrm{m}^2\mathrm{s}^{-1}$. We used the latter value to minimise node-to-node oscillations.

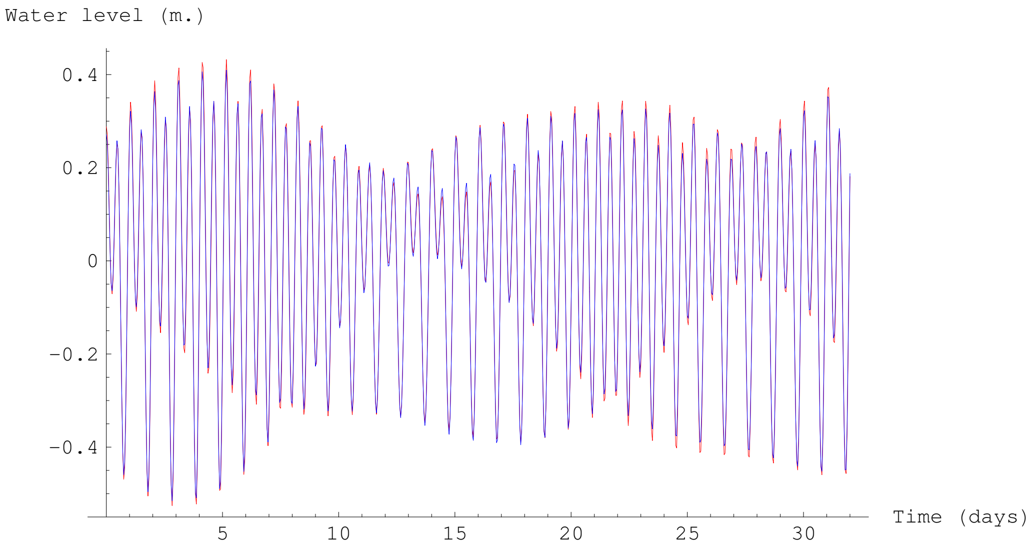

Figure 2: Water level (m) as a function of time at Queenscliff over 32 days. Observed data is a green line while modelled data is a blue line.

3 Existing data

Our results for the amplitude and phase of the tide at seven locations in the bay (Pt. Lonsdale, Queenscliff, Hovell Pile, West Channel Pile, Pt. Richards Channel No. 1, Geelong and Williamstown) were obtained by analysing the data over 29 days using the Fourier Transform, and compared with the observed data and at five locations compared with those of Lawson and Treloar [5] and Walker [9]. Our results for the vector differences are in good agreement with those of Lawson, Treloar and Walker. Perhaps the results would have been better if more constituents were used. The vector difference is obtained by regarding each constituent as a vector, with its magnitude equal to the amplitude of the constituent and its phase the phase of the constituent. The vector difference is the magnitude of the vector joining the ends of the modelled vector and the observed vector. As our modelled values for the existing tide are close to those of the observed values, our prediction on the effects of the astronomical tides of post-channel deepening should be accurate. Our model is neither inferior nor superior to the other two. Figure 1 shows the bathymetry together with the seven locations. Figure 2 graphs the observed and modelled water level at Queenscliff. Lastly, Figure 3 shows the contour lines for amplitude of the modelled M_2 component.

4 Post channel deepening data

Increasing the depth of the channel at the entrance to the Bay will increase the volume of water flowing into the Bay. Our numerical model shows tidal levels increase at most locations and decrease at others. We compared our modelled existing tidal levels at the seven different locations with our modelled post-channel deepening tidal levels and compared these results with those of Lawson and Treloar [6]. The results at five locations are shown in Table 1. See that our results are in close agreement with those of Lawson and Treloar for amplitude change. Our results for phase change are in good agreement with those of Lawson and Treloar at West Channel Pile, Geelong and Williamstown. There is some discrepancy in the results for phase change at Queenscliff and Hovell Pile although the differences are small.

The values shown in Table 2 were calculated using the experimental data for the observed present tide (called E), our modelled present tide (called M) and our modelled post-channel deepening tide (called P). The values M and P were calculated using only M_2, S_2, N_2, K_1 and O_1 components. Because our model of the existing tide is slightly inaccurate the change in tidal height is estimated by $(E/M)P - E$.

Table 1: Comparison of tidal constituents between modelled existing and modelled post channel deepening

Tidal constituent	Amplitude change (m)		Phase change (degrees)		Vector difference (m)	
	This study	Lawson & Treloar	This study	Lawson & Treloar	This study	Lawson & Treloar
Geelong						
M_2	+0.004	+0.005	+0.1	0.0	0.004	0.005
S_2	+0.001	+0.001	+0.1	+0.1	0.001	0.001
N_2	+0.000	+0.001	+0.2	0.0	0.000	0.001
K_1	+0.001	+0.002	−0.4	−0.4	0.001	0.002
O_1	+0.001	+0.001	−0.5	−0.3	0.001	0.001
Queenscliff						
M_2	−0.002	0.000	+0.6	−0.1	0.003	0.001
S_2	0.000	0.000	+0.5	−0.2	0.001	0.000
N_2	0.000	0.000	+0.7	+0.3	0.001	0.000
K_1	0.000	0.000	+0.3	−0.2	0.001	0.000
O_1	0.000	0.000	+0.4	+0.2	0.000	0.001
Williamstown						
M_2	+0.004	+0.004	−0.1	0.0	0.004	0.004
S_2	+0.001	+0.001	+0.1	+0.1	0.001	0.001
N_2	0.000	0.000	+0.2	0.0	0.001	0.000
K_1	+0.001	+0.002	−0.4	−0.4	0.001	0.002
O_1	+0.001	+0.002	−0.5	−0.3	0.000	0.002
Hovell Pile						
M_2	+0.003	+0.004	0.0	−1.4	0.003	0.006
S_2	+0.001	+0.001	+0.2	−1.9	0.001	0.002
N_2	+0.001	+0.001	+0.3	−1.6	0.001	0.001
K_1	+0.002	+0.002	−0.4	−1.2	0.002	0.003
O_1	+0.001	+0.002	−0.5	−1.1	0.001	0.002
W. Ch. Pile						
M_2	+0.005	+0.004	+0.1	+0.1	0.005	0.004
S_2	+0.001	+0.001	+0.2	+0.2	0.001	0.001
N_2	+0.001	+0.002	+0.1	+0.1	0.001	0.000
K_1	+0.001	+0.002	−0.4	−0.4	0.002	0.002
O_1	+0.002	+0.002	−0.5	−0.2	0.002	0.002

Figure 3: The contours of amplitudes of the modelled M_2 component.

Table 2: Modelled changes in maximum tidal height at various locations due to the channel deepening

Location	Change in max tidal height (m)	
	This study	Lawson & Treloar
Point Lonsdale	−0.001	
Queenscliff	−0.002	−0.002
Hovell Pile	+0.007	+0.005
West Channel Pile	+0.006	
Point Richards Channel No. 1	+0.007	
Geelong	+0.006	
Williamstown	+0.006	+0.008

5 Conclusions

We conclude that the effect of the proposed channel deepening on astronomical tidal levels in Port Phillip Bay will be to increase the maximum tidal height at most locations, with the largest increase in maximum tidal height predicted to be seven mm. Our results are in close agreement with those of Lawson and Treloar [5, 6], who found that the maximum tidal height will increase at most locations, with the largest increase in maximum tidal height predicted to be eight mm.

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