29. October 2009

Seiche in Lyttelton Harbour

1. Introduction

This brief report describes the seiche[1] that occurs in Lyttelton Harbour. The work was initiated in an effort to explain why dredge-spoil dumped on the north side of the harbour in Gollans and Mechanics Bays seems to always end up in the shipping channel opposite Livingstons Bay (Figure 1). The hypothesis was that there may be an antinode at Livingstons Bay where the velocities cancel out causing sediment to fall out of suspension.

A long, narrow harbour like Lyttelton will typically have a node at the entrance where the seiche amplitude is zero, and may have several more nodes in the harbour. Under these nodes, the velocities can be large, but between them there will be antinodes where the velocity is zero. The objective of this study was to investigate whether such an antinode occurs in the vicinity of Livingstons Bay.

Figure 1. Lyttelton Harbour showing: (i) the sites referred to in the text; (ii) the location of the tide gauge; and (iii) the thalweg used in the seiche model.

1 Seiche is a Swiss word of unknown origin that has been used for centuries to describe the tide-like oscillations of Lake Geneva. Nowadays, it is used to describe the oscillation of any body of water at its natural frequency.

2. Extracting the Seiche

A typical portion of data from the tide gauge situated at the Tug Berth (Figure 1) is shown in Figure 2. The dominant feature of this record is the tide, but the shape is by no means sinusoidal: it appears to be highly distorted. This is the effect of the seiche.

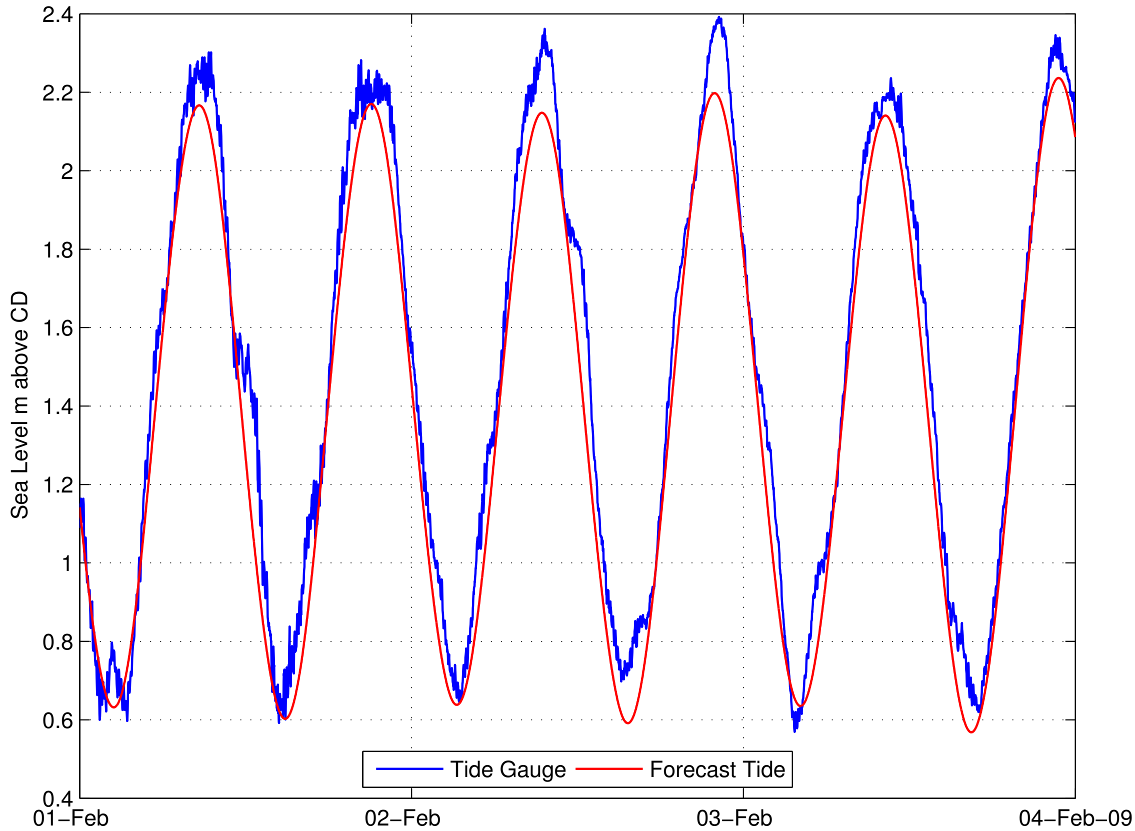

Figure 2. Typical period of record from the Lyttelton tide gauge compared with the forecast tide.

Extracting the seiche from a record such as that shown in Figure 2 involves removing the tide, then for each day of data calculating the Fourier spectrum and averaging these over at least six months of data. Averaging has the effect of eliminating the effects of storms and calm periods, and the resulting mean daily spectrum reveals the seiche periods as a series of spikes, as shown in Figure 3.

The Fourier spectrum is a representation of how energy in a signal is distributed with period. Traditionally, the spectrum is plotted in log-log space with period increasing to the left.

3. Analysis of the Seiche

Figure 3 has three significant spikes at: 205, 99, and 10 minutes. These are the seiche periods of the harbour. Energy entering the harbour at these periods, such as occurs in a tsunami, will be amplified many-fold causing what is called “harbour resonance”. This is what led to the waves of up to 6 m in height in the harbour from the Chilean tsunami of 1960.

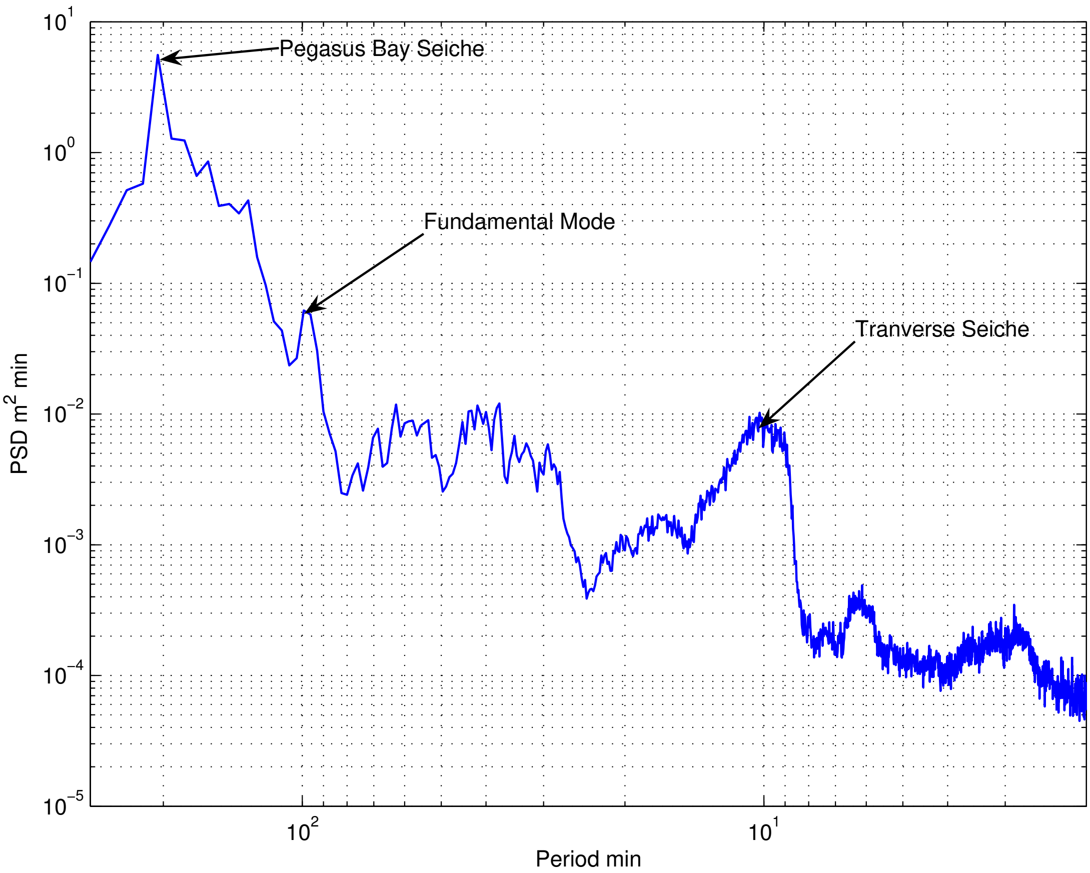

Figure 4. Mean daily Fourier spectrum

The 205-min seiche has been studied previously by Goring & Henry (1998)[2] who showed that it corresponds to oscillations of the whole of Pegasus Bay from the shoreline out to the continental shelf. It is ubiquitous, being driven by the interaction of tide and weather systems as they propagate over the continental shelf and into the bay. These fluctuations in sea level are amplified by the harbour, as shown in Figure 4 which compares the Lyttelton spectrum with the spectrum for NIWA's sea-level recorder at Sumner Head outside the harbour. The amplification in energy is 2.7 times the energy, which is equivalent to 1.7 times the amplitude.

The 99-min seiche corresponds to the fundamental or sloshing mode of the harbour, as will be shown in the next section. The spectrum for Sumner Head also has a peak near this period, but it is at 96 min which is significantly different from the 99-min seiche of the harbour, so it is likely to have a different source.

The 10-min seiche is likely to be a tranverse oscillation between the entrance to the Inner Harbour and Diamond Harbour.

2 Goring, D. G.; Henry, R. F. 1998: Short period (1-4h) sea level fluctuations on the Canterbury coast, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 32: 119-134.

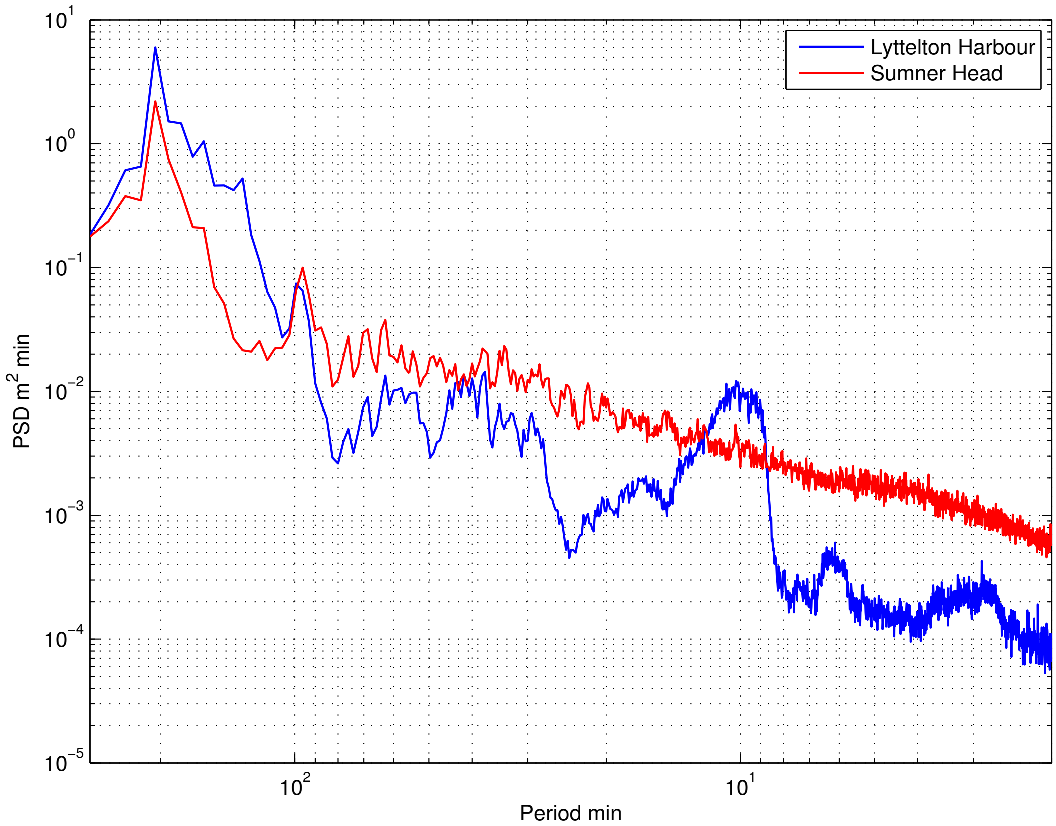

Figure 4. Comparison of the long-wave spectrum in Lyttelton Harbour with the spectrum at Sumner Head.

4. Seiche Model

Wilson (1972)[3] presents a method to model a harbour such as Lyttelton using a finite difference technique. The data requirements are the cross-sectional area and the surface width along the length of the harbour. For Lyttelton Harbour, these data were derived by digitising a series of points along the thalweg (see Figure 1), by recording the depth and the distance to the shore on either side. A quartic cross-section was assumed, meaning that the cross-sectional area was 4/5×Depth×Width. The model results in an eigenvalue problem whose solution yields a set of eigenvalues (the seiche periods) and corresponding eigenvectors (the shape of the sea surface from the entrance to the head of the harbour).

The first few seiche periods that emerge from the model are listed in Table 1 and the shape of the eigenvectors is shown in Figure 5. The curves show the envelope of oscillations along the harbour. Thus, for example, considering the 3rd mode, Livingstons Bay has a node where the amplitude of the seiche is largest, whereas the tide gauge has an antinode where the amplitude of the seiche is almost zero.

4.1 Validation of the Model

The first or fundamental mode has a gradually increasing range as we go up the harbour, the range at the head of the harbour being 1.9 times the range at the tide gauge. The period for the fundamental mode (102.3 min) is close to the period calculated from the data (99 min), verifying

3 Wilson, B. W. 1972: Seiches. In: *Advances in Hydroscience, Vol 8*: 1-94.

the accuracy of the model.

The period for the 2nd mode (39.3 min) corresponds to a broad crest in the spectrum (Figure 2); whereas, the period for the 3rd mode (25.5 min) has a trough in Figure 2 indicating no energy at that period. However, Figure 5 shows that there is an antinode (zero amplitude) for the 3rd mode at the tide gauge. Hence, we would not expect to find a peak in the spectrum at that period.

From this comparison, we can conclude that the model is accurately representing the longitudinal seiche in the harbour.

Table 1. Seiche periods (min) calculated from the Wilson model.

Eigenvalue Number					
1	**2**	**3**	**4**	**5**	**6**
102.3	39.3	25.5	17.8	14.6	11.5

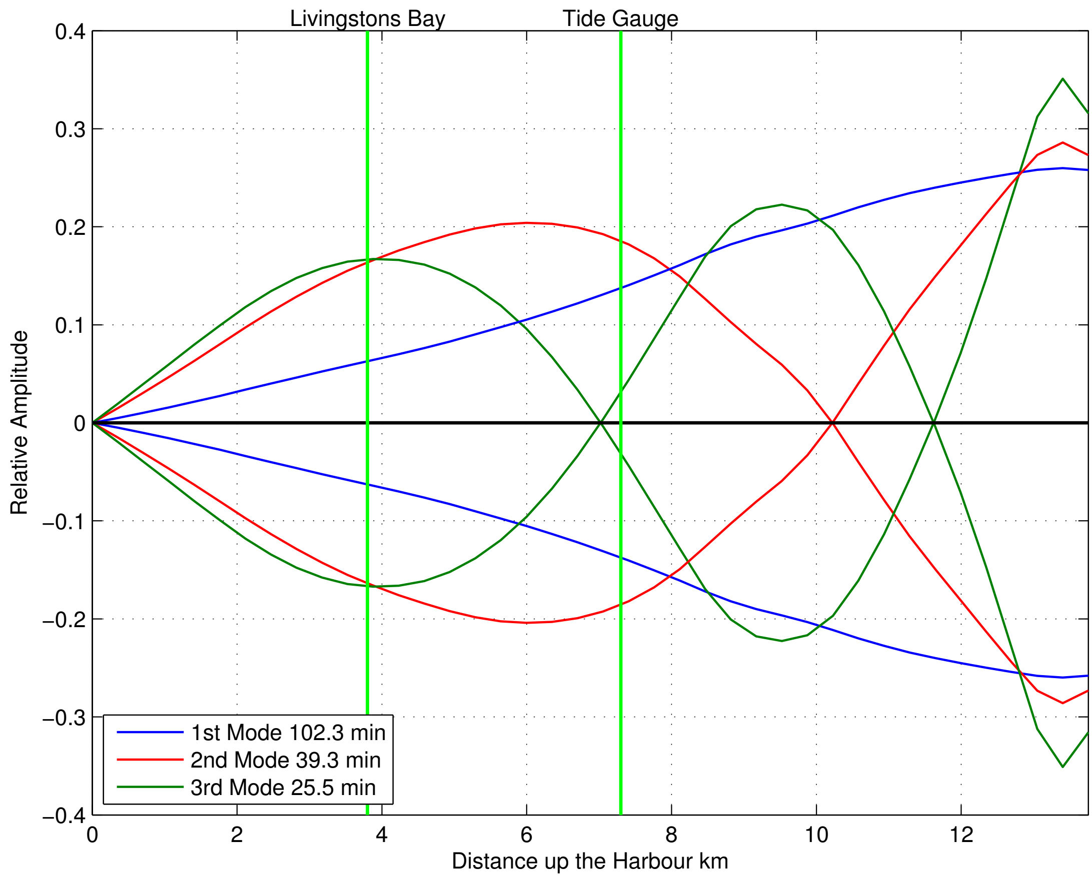

Figure 5. The first few eigenvectors showing the range of oscillations of water level with distance from the entrance of the harbour.

5. Discussion

Figure 5 shows that at Livingstons Bay, there is indeed an antinode in the longitudinal seiche where the velocity goes to zero. However, it is in the 3rd mode which is expected to have less energy than the first two modes, so the question that arises is whether the increased sedimentation observed in the vicinity of Livingstons Bay can be attributed to that mode.

Unfortunately, the eigenvalue model described in Section 4 gives no information on the strength of a particular mode, and the measurements at the tide gauge are not helpful because it is situated at a node where the amplitude of the 3rd mode is zero.

One way to resolve this dilemma is to place a tide gauge at Livingstons Bay for a few weeks and compare the long-wave spectrum with the spectrum at the tide gauge. If there is significant energy in the vicinity of 25-min period, we can conclude that the 3rd longitudinal seiche mode of the harbour is a likely reason for the increased deposition at Livingstons Bay.

6. Conclusions

In this study, we examined the seiche patterns in Lyttelton Harbour in an effort to explain why the deposition of sediment in the vicinity of Livingstons Bay is greater than at other locations. We found that at this location there is indeed an antinode where the seiche velocity is zero, but it is in the 3rd mode of oscillation, which usually has less energy than other modes.

We conclude that seiche could be the reason for increased deposition at Livingstons Bay, but measurements by a tide gauge at the site are required to confirm this.

Derek Goring
Mulgor Consulting Ltd
d.goring@mulgor.co.nz