MORPHODYNAMIC MODELLING FOR THUAN AN INLET, VIETNAM

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Abstract: Thuan An is a tidal inlet located in Vietnam in a tropical monsoon area. The inlet is very dynamic and variable under the influences of not only tides and waves from the sea but also flows and floods from upstream rivers. Therefore, morphodynamic behaviour of the inlet is very complicated and not well understood. Studies on inlet are also facing with problems of data insufficient. As an effort to gain more understanding on the tidal inlet behaviour, this paper presents a study of the inlet morphodynamics using a numerical modelling approach with the applications several modelling packages including DELFT3D and SOBEK-RURAL developed by WL|Delft Hydraulics. SOBEK has been used to simulate properly the floods in the rivers and on the floodplain. DELFT3D has been used to simulated hydrodynamics of the coastal waters and morphodynamics of the inlet. From the results of the numerical modelling experiments, some behavioural patterns of the inlet, like migration of the inlet channel, can be explained.

Keywords: tidal inlet, hydrodynamics, morphology, numerical modelling

1. INTRODUCTION

The Thuan An inlet belongs to a double tidal inlet system connecting a large lagoon in the Central Coastal Area of Vietnam to the sea (Figure 1). Morphodynamics of the inlet have a seasonal closing characteristic and influenced by tropical monsoon climatic conditions. The inlet is located in a microtidal area with the tidal range less than 0.5 meters so the influence of wave action becomes dominant. Especially, during the dry season lasting for 8 months when river inflows are small, a large amount of sediment transported due to waves enters the inlet makes inlet shoal and unstable. With a total longshore sediment transport towards the inlet $M_{tot}$ of about $1.6\times10^6 m^3$ and $P/M_{tot}=30$ (Lee, 1970), the inlet is categorized to a “fair to poor” stability situation according to (Bruun, 1978) with entrance shoals and inlet migration. In the rainy season, inlet morphology is even more dynamic and is dramatically changed due to flood flows from upstream rivers. During the floods, the cross-section of the inlet is widened deepened by high flow velocities from the rivers. Also, breaching of the narrow sand barrier may happen. Morphological behaviour of the inlet, such as inlet channel migration (Figure 2), is complicated and not well understood. To gain a better understanding on the morphodynamics of the inlet, especially, the migration of the Thuan An inlet channel, this study is carried out using a numerical modelling approach with the applications of Delft3D and Sobek-Rural.
2. NUMERICAL MODELLING APPLICATIONS

1. Model domains
   To study the system and its behaviour, much data of hydrodynamics is required. On the seaside, information on water level, tides, waves, currents, and sediment transports are required for different seasons including extreme conditions of typhoons. On the landside, water levels, flow discharges and sediment transports from the rivers are required for different seasons including extreme conditions of floods and overland flows on the floodplain. Unfortunately, for this case, such kind of basic data is very limited. In the inlet vicinity, data is available in very short periods. Longterm observations of tides and waves are available only at Da Nang and Con Co Island which are about 80 kilometers far away from the inlet (Figure 1). In the rivers, observations of flow discharge and water level are only available at upstream locations which are also far away from the inlet. These available data can be used as boundary conditions for the study of the inlet. But one could not include all to only one model due to limitations of available modelling tools. To overcome these limitations, the model nesting technique is used to transform to the inlet area the information at the locations which data available. In this approach, three different type models are used including:
   - Model A for the coastal and continental shelf waters.
   - Model B or C for the river and lagoon system.
   - Model D as detail model for the Thuan An inlet.

   The models and domains are shown in Figure 3.

Model A
   This model is setup using Delft3D to produce seaside boundary conditions for the inlets like tides, typhoon surges, wind-induced currents, waves. The simulation model is based on Delft3D package with a key module of Delft3D-FLOW. Other modules, e.g. Delft3D-WAVE, Delft3D-MOR, are used when necessary.
Input for the model is mainly a set of tidal components at sea boundaries. In some simulations, other inputs are winds, waves, or typhoon wind and pressure fields. Results of the model are used as boundary conditions for other models of B, C, D, and E.

The domain of the model is selected large enough to reduce effects of uncertainty at the boundary to the inlet area. For examples, typhoon surges and ocean currents are normally unknown in the inlet areas and require to be simulated properly. Therefore the model boundaries should far away from the inlets at least the radius of typhoon’s maximum wind speed (about 50km to 70km). For that reason, the model boundaries are selected far away from the inlets 100km at the deep water of 100m offshore. The model grid includes 161x297 nodes with the minimum grid size of 150m at the inlet and the maximum grid size of 1600m at the offshore boundary. Tidal boundary of the model is divided into 7 sections (Figure 3).

![Figure 3](image-url)  
**Figure 3.** Model domains for the coastal waters and tidal inlets

The model is calibrated for the periods assuming that only tidal forcing is relevant. The influences of river inflows and inlet geometry are neglected and is considered in the detailed model. Boundary conditions of the model are taken from global ocean tide models. Several datasets from the global ocean models such as NAO.99b (Matsumoto et al., 2000), GOT00.2 (Ray, 1999), CSR 4.0 (Eanes et al., 1996; Eanes, 2002) and TPXO6.2 (Egbert et al., 1996; Egbert et al., 2002) have been used as boundary conditions. These models are based on TOPEX/Poseidon altimetry and generate good tidal predictions for deep water areas. All of these models do not give results of long-term and shallow water tidal components for the area.
During model calibration, results of the model are compared with harmonic constants available from observed tides at five locations of Con Co, Da Nang, Cu Lao Cham, Chan May and Thuan An. The main tidal components for the area are K1, M2, O1, S2 and Sa. There are seasonal changes of water level at these locations at the order of 0.2 meters and can be assigned to the one-year-cycle tidal component Sa.

Among the global ocean models, only the datasets from GOT00.2 and NAO.99b produce reasonable results which GOT00.2 has the best fit with tidal observations in both amplitudes and phases of tidal constituents. Model results of water level at the inlets have a good agreement with observed data (Table 1).

<table>
<thead>
<tr>
<th>Tidal wave</th>
<th>Con Co</th>
<th>Da Nang</th>
<th>Cu Lao Cham</th>
<th>Chan May</th>
<th>Thuan An</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_{obs}</td>
<td>0.057</td>
<td>0.187</td>
<td>0.163</td>
<td>0.230</td>
<td>0.160</td>
</tr>
<tr>
<td>H_{cmt}</td>
<td>0.101</td>
<td>0.163</td>
<td>0.210</td>
<td>0.160</td>
<td>0.109</td>
</tr>
<tr>
<td>H_{obs}</td>
<td>0.189</td>
<td>0.168</td>
<td>0.170</td>
<td>0.170</td>
<td>0.170</td>
</tr>
<tr>
<td>H_{cmt}</td>
<td>0.197</td>
<td>0.188</td>
<td>0.193</td>
<td>0.183</td>
<td>0.183</td>
</tr>
<tr>
<td>O1</td>
<td>0.136</td>
<td>0.119</td>
<td>0.176</td>
<td>0.090</td>
<td>0.051</td>
</tr>
<tr>
<td>P1</td>
<td>0.019</td>
<td>0.055</td>
<td>0.070</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S2</td>
<td>0.061</td>
<td>0.055</td>
<td>0.070</td>
<td>0.030</td>
<td>0.062</td>
</tr>
<tr>
<td>M4</td>
<td>0.002</td>
<td>0.000</td>
<td>0.000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MS4</td>
<td>0.005</td>
<td>0.000</td>
<td>0.000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sa</td>
<td>-</td>
<td>0.181</td>
<td>0.182</td>
<td>0.181</td>
<td>0.181</td>
</tr>
<tr>
<td>R</td>
<td>0.98</td>
<td>0.98</td>
<td>0.97</td>
<td>0.85</td>
<td>0.98</td>
</tr>
</tbody>
</table>

**Table 1.** Observed and computed amplitudes of tidal constituents (\(H_{obs}\) and \(H_{cmt}\) in meters, respectively) and their correlation coefficient R at some locations.

Model B and C

Maximum flow discharge at the Thuan An inlet is about 3000 m³/s in the dry season. During a floods this value may be as high as 13000 m³/s cause very high flow velocity in the inlet (Lam, 2002). Therefore river flow plays an important role on the inlet morphodynamics. Model B and C are setup to reproduce influences of upstream rivers on the inlets (Figures 4 and 5). These models use observation data at gauging stations or other hydrologic models as upstream boundary conditions. Results of sea water levels from Model A are used as downstream boundary conditions. The models provide results as flow discharges and water levels at the inlets.

![Figure 4](https://via.placeholder.com/150)

**Figure 4.** Model B of the river, floodplain, lagoons and tidal inlets using Sobek-Rural

![Figure 5](https://via.placeholder.com/150)

**Figure 5.** Model C of the river, lagoons and tidal inlets in dry season using Delft3D

Model B is used for routing flows in the rivers and floodplain to the inlets using Sobek-Rural. To simulate properly flows in both the rivers and on the flood plain, a 1D-2D coupling
model of Sobek-Rural is used with two modules: 1D channel module for the river system and 2D overland module for the flood plain.

Topographic data for the 2D module is a DEM of 200m resolution constructed from topographic maps for the lowland area. In the hilly and mountainous areas, only 1D model of river channels is used (Figure 4).

Upstream boundary locations for the model can be selected at the locations where historical data available. Downstream boundary conditions for the model are the results from Model A. Observed water levels at the gauging stations inside the model domain are used for model calibration and verification.

The model has been calibrated and validated for some historical floods which observed data is available. Because SOBEK 1D2D has a capability of presenting well 2D overflows on the flood plain, results of the model in 2D case show the best agreement with the observations in comparison with all other 1D models (SOBEK 1D, DUFLOW, HEC-RAS, VRSAP) have been used for the area. In 1D models, the flood plain can only be simulated as the storage areas.

![Figure 6. Inundation during the flood of November 1999 from RADARSAT imagery](image)

![Figure 7. Flooding simulation using Sobek-Rural coupling 1D2D for the flood of November 1999](image)

Model C is setup based on Delft3D for properly simulating hydrodynamics of the lagoon and tidal inlet system in the dry season.

**Model D**

Model D is the detailed model for the morphodynamics of the Thuan An inlet based on Delft3D using Delft3D-FLOW and Delft3D-MOR modules (Figure 8). This model aims to study morphological behaviors of the inlet under influences of boundary conditions taken from above models. Results from Model A are used as sea boundary conditions. Results from Model B and C are used as river boundary conditions.

Model simulation for the historical flood of November 1999 shows that flow velocity in the Thuan An inlet may reach 2.5 to 3.0 m/s and forms flow jets in the channel. These high velocity flow jets widen and deepen the inlet cross-section and change the inlet channel in the ebb delta. Therefore, a strong jet flow in the floods is responsible for maintenance the inlet channel and the ebb tidal delta. In the near field of the jet flow during a flood, direction of flow is stable, the changes are mainly in magnitude. In the far field, not only magnitude is changing but also direction of the flow is also changing corresponding to the changes of ocean tides. The morphological simulation also produces the change of the inlet topography caused by the flood has a good agreement with reality (Figures 9, 10 and 11).
From experiments of changing boundary conditions in the model, it is found that the change in the direction of the inlet channel is determined by the flow distribution of the different rivers. The direction and migration of the inlet channel depends on the dominant contributions of flows coming from the rivers on the northern side or southern side of the inlet (Figure 12). If flood water coming from the southern side of the inlet is dominant, the direction of the inlet channel will head to north. If flood water coming from the northern side of the inlet is dominant, the direction of the inlet channel will direct to northeast.

The sole influence of the flood flows on the inlet channel also explains the absence of the flood tidal delta inside the lagoon. In the floods, sediment from the channel and inside the lagoon is transported to the ebb delta. In the dry season, sediment transported by longshore currents enters the inlet and deposits the channel but tidal currents are too weak to transport sediment further inside the lagoon to build up the flood delta.

Another result found from the model is the dominant sediment transport nearshore in the southeast – northwest direction caused by the asymmetry of the ocean tides.

Figure 8. Detail model domain of the Thuan An inlet (Model D)

Figure 9. Bathymetry of the Thuan An inlet surveyed in 2002

Figure 10. Bed topography of the inlet before the flood November 1999

Figure 11. Simulated bed topography of the inlet after the flood November 1999
3. CONCLUSION

Morphodynamics of the Thuan An inlet has been studied using appropriate numerical models and the model nesting technique to overcome the complexity of the governing processes and limitations of available data. Some morphological characteristics and behaviours of the inlet, like the absence of the flood delta and the migration of the inlet channel, can be explained. From morphological modelling experiments for the Thuan An inlet, it has been found that the inlet is mainly maintained by high velocity flow jets in the river floods and the change in the direction of the inlet channel is influenced by the distribution of river flows coming from different tributaries. Further more, longshore sediment transport in the area has also a contribution by tidal asymmetry in the ocean.

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