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Similarities between Yangshan Harbor area and the Yangtze estuary

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(State Key Laboratory of Estuarine & Coastal Research, East China Normal University, Shanghai 200062, China) Abstract: By analysis of published papers on the Yangtze estuary and hydrological and sediments data in Yangshan Harbor area, many similarities are found between Yangshan Harbor area and the Yangtze estuary. These similarities include the phenomenon of stagnating flow areas, the distributive characteristics of the highest suspended sediment concentration areas, superficial sediments and shoal bars. The stagnating flow area is the major similarity which causes other similarities. These similarities indicate that: 1) Turbidity Maximum and mouth bars in estuaries are mainly caused by the hydraulic balance of stagnating flow areas of estuaries; 2) The stagnating sand area of sands caused by stagnating flow area often locates on the narrower side of the stagnating flow area; 3) The location (or shape) of fine sediments area caused by stagnating flow area reflects the location (or shape) of the stagnating flow area. Both Yangshan Harbor area and the Yangtze estuary are the important developmental areas in the future (man-made similarity). In-depth studies on these similarities between Yangshan Harbor area and the Yangtze estuary will have momentous theoretical and practical significance. CLC number: P731.2; P736.2 1 Introduction Yangshan Harbor, which will be built soon, is the large-scale International Deep Harbor of Shanghai city. It is located in Qiqu Archipelago which is both at the mouth of Hangzhou Bay and on the southern offshore edge of the Yangtze (Changjiang) estuary (Figure 1). Qiqu Archipelago is group of the islands nearest to Shanghai city land. The distance between Yangshan Harbor and Shanghai´s Luchao Harbor is about 30 km. Qiqu Archipelago, a part of Zhoushan Archipelago, consists of over 60 islands. These islands are like two chains, one is at the north and the other at the south. The area between the two chains is like a channel. The channel and its adjacent sea area are the study area "Yangshan Harbor area". Before the 1990s, few studies were carried out on Yangshan Harbor area so its characteristics were largely unknown. During the 1990s, China decided to build the Shanghai International Navigation Center. In order to choose a beneficial site of the future Deep Harbor, much attention is paid on Yangshan Harbor area for its short distance and deep water. Researches have been gradually carried out on this area which is finally chosen to be the suitable site. So few people learn its characteristics. Since October, 1996, four large-scale hydrological and sediments investigations have been carried out on Yangshan Harbor area and some related themes on the future Deep Harbor have been discussed (Cheng, 2000a, b; Jiang et al., 2000; Xie et al., 2000; Xu, 2001; Yan, 2000; Yang and Feng, 2000). But research is needed into the regularity of the hydrological characteristics and sediments transportation. This paper indicates that there are many important similarities between Yangshan Harbor area and the Yangtze estuary. Further study also indicates that these similarities are not accidental, but are due to the similarity in hydrological characteristics. Today, some scholars concentrate on comparing different estuaries in order to investigate the substantive causes of some important phenomena (e.g. Turbidity Maximum) in estuaries (Grabemann et al., 1997; Mao and Shen, 2001; Shen et al., 2001). This paper extends the comparative region and makes comparison between non-estuary and estuary. It is beneficial both to research the main cause of these phenomena, but also for Yangshan Harbor to take advantage of what is known about successful estuarine achievements. Since in-depth studies have been done on the Yangtze estuary, this paper will pay more attention to Yangshan Harbor area and less to the Yangtze estuary. The study area "Yangshan Harbor area" is between 121o56´50´´-122o14´E and 30o32-30o42´N, about 28 ×18 km2. The current data of 11 stations were measured in October, 1996 by SLC9-2 current meters, at different water depths, i.e. surface, 0.2H, 0.4H, 0.6H, 0.8H and bottom (Here, H is the total water depth in on e station). Current measurement time is 27 (or 28) h successively which have 1 h or 0.5 h intervals. Current measurement was carried out at spring, normal and neap tide respectively. Water samples are collected simultaneously with current observation at different water depths. Suspended sediment concentration (SSC) and grain size in water samples are analyzed. Salinity data were measured in September, 1997, at every station and at spring, normal, neap tide respectively. Some 461 superficial sediments were grabbed by a Clam-like Grab at 1 km squared interval (other grabbed samples which are beyond the study area will not be taken into account) and the sampling depth was between 5 cm and 10 cm. If islands were on the sampling points, the samples would be grabbed around the planned point within 500 m. The grain sizes of superficial sediments were analyzed by dry-sieve and pipette method. Superficial sediment types are classified by dredge sediments criterion. Wave data are based upon Daqi (in the northeast of Qiqu Archipelago) wave data covering 1982-1983 and Guanyinshan (in the south of Xiaoyangshan) wave data covering 1997-1998. 2 Physical setting in Yangshan Harbor area As mentioned above, the islands of Qiqu Archipelago are like two chains. The strike of the northern islands chain is NW-SE, while the southern islands chain is E-W. The minimum breadth between the two chains is about 1 km, and the maximum is about 7 km. The water area between the two chains has many characteristics typical of islands-chain channel. Many inlets are beside the channel and they are the exchange passages of water and sediments between the channel and the sea outside Qiqu Archipelago. The water depth outside Qiqu Archipelago is about 7-10 m, while affected by a strong current and the channel´s effect (Chen, 2000a), the water depth in the west of the channel is mainly 9-10 m and in the east is more than 30 m. The current field in Yangshan Harbor area is mainly controlled by tide and strongly affected by islands´ topography (especially the channel´s topography). Wave and river runoff have little influence on the current field. The tide in Yangshan Harbor area is an irregular semi-diurnal tide and mainly controlled by Donghai forward tide in which M2 constituent is the main component. K1 and O1 constituents are secondary. Mean tidal range is 2.79 m and the maximum tidal range is 4.28 m (Chen, 2000a). The main direction of tide current is NWW-SEE which is close to the channel´s strike, so ebb currents are directed and contracted strongly. The channel is like a westward trumpet, those inlets beside the channel draw currents into the channel at flood tide and divert currents from the channel at ebb tide. Compared with other coastal sea areas in China, the current velocity in Yangshan Harbor area is fastest. The max current velocities at flood and ebb tide are 121-255 cm/s and 222-309 cm/s respectively (Table 1). The mean current velocities at spring, normal and neap tide are 112 cm/s, 100 cm/s and 73 cm/s respectively. Mean flood and ebb tide times are 5 h 47 min and 6 h 40 min respectively. Ebb current is dominant. Waves in Yangshan Harbor area mainly consist of wind waves which have distinctly seasonal variation (e.g. strong in winter and weak in summer in general). Mean wave height in winter is 1.0 m with northern and northwestern directions in the majority, while in summer it is 0.8 m with southern and southwestern directions in the majority. Within Qiqu Archipelago, waves are weak, its period is short and mean wave height is only 0.4 m. For the deep water depth within Qiqu Archipelago, relatively little influence is produced by waves. Suspended sediment concentration (SSC) in Yangshan Harbor area is dense for strong currents and SSC has a high positive correlation with current velocity (Chen, 2000c). Based upon data at 11 stations, vertical-average SSC in winter at spring, normal and neap tide is 2.177 kg/m3, 1.872 kg/m3 and 0.479 kg/m3 respectively (Xie et al., 2000). SSC in winter is denser than it is in summer. At spring tide, SSC is 2.177 kg/m3 in winter and 1.690 kg/m3 in summer (Xie et al., 2000), which has a positive correlation with wave intensity and no positive correlation with quantity of suspended sediment discharged by the Yangtze River (Chen, 2000c). Therefore the variation of SSC in Yangshan Harbor area is basically determined by bed material re-suspending. Salinity in Yangshan Harbor area is governed by the dilution of sea water by the Yangtze River, the Qiantang River and other rivers. Usually, the minimum salinity occurs in October and the maximum in March. Based upon salinity data at 11 stations in September, 1997, vertical-average salinity was 10.88-22.85‰ among all types of tides. At spring tide, average of vertical-average salinity is 13.22-17.00‰ while at neap tide it is 15.24-18.78‰ which is higher than at spring tide. Vertical mixing coefficients of salinity at all stations are all >0.76, belonging to the type of strong mixture. Yangshan Harbor area is located in the southward diffusing scope of Yangtze diluted water. Suspended sediments carried by diluted water are the main material source of fine sediments in Yangshan Harbor area. Coarse sediments in Yangshan Harbor area are mainly supplied by weathering products of islands there (Chen, 2000c). The Qiantang River, the main river entering Hangzhou Bay, has little influence on Yangshan Harbor area (at the mouth of Hangzhou Bay) for its runoff and sediment discharge are only 4.2% and 1.4% of the Yangtze River respectively (Su and Wang, 1989). 3 Similarities between Yangshan Harbor area and the Yangtze estuary 3.1 Similarity in hydrological characteristics Flocculation of fine sediments in the mixing area between fresh water and sea water may be helpful to TM formation. But in Yangshan Harbor area, flocculation is weak for relatively high salinity and strong currents (Yan, 2000). Even if it has any influence, the influence may be approximately same to each station for the salinity range there is small among these stations and salinity mixing is intense. So, without the help of flocculation, TM can also be formed by dynamic balance of the stagnating flow area. The theory of estuarine circulating currents argued that "there are generally seaward residual flow in superficial water and landward residual flow in bottom water in estuaries. The two opposite residual flows form a circulating current in vertical direction. The circulating current may be the main cause of TM in estuaries". As mentioned above, ebb current is dominant in general in Yangshan Harbor area, especially in superficial water. If dominant flow in lower water is flood current in one place, a circulating current of vertical-direction residual flow often occurs there, such as Q4, Q5, Q9 at spring tide and Q2, Q3, Q5, Q7, Q8 at neap tide. But the highest SSC areas only take place in Q4 at spring tide and Q5, Q7 at neap tide. In other words, even if no circulating current of vertical-direction residual flow, SSC there may be higher. Even if existing circulating current of vertical-direction residual flow, SSC there may be lower. Therefore, the circulating current of vertical-direction residual flow has no necessary correlations with TM. In fact, river water will eventually flow into the sea and there is a density difference between fresh water and sea water, so the circulating current of vertical-direction residual flow must happen in estuaries. Therefore, the circulating current of vertical-direction residual flow and TM are two coexisting phenomena in estuaries, but no necessary relations exist (If comparison is only carried out among different estuaries, it may be difficult to discern this relationship between TM and the circulating current of vertical-direction residual flow). Another opinion argued that TM is the result of bed sediments re-suspending. It may be imperfect. This opinion simultaneously involves two conditions of TM formation (i.e. fine sediments´ source and dynamic mechanism). Firstly, it indicates that bed sediments are the main material source of TM in estuaries, which is identical with the situation in Yangshan Harbor area. Secondly, it reveals that bed sediments re-suspending is the essential dynamic mechanism of TM formation. However, bed sediments re-suspending exists in all water area, if it is the main dynamic mechanism, current velocity in TM should be faster than around there (Only faster current velocity can produce higher SSC). But it is not true in Yangshan Harbor area. Figure 2 indicates that current velocities in high SSC area are moderate among all stations at spring tide (i.e. Q2, Q3) and are minor at neap tide (i.e. Q4, Q5, Q6, Q7). Therefore, bed sediment re-suspending is not the essential cause of TM formation. It is only the main cause of the situation that SSC in Yangshan Harbor area changes with current velocity in general. It is also the necessary dynamic process of lifting bed sediments. This phenomenon also indicates that if a quantitative relationship between current velocity and SSC is identified without taking into account the dynamic characteristics of stagnating flow area, significant variance may be resulted in. TM needs a dynamic mechanism of fine sediments converging in it. Fine sediments themselves already have merits of easily suspending and hard depositing. If the dynamic mechanism mentioned above also exists, TM must happen. This requirement is satisfied by dynamic balance in stagnating flow area. In conclusion, dynamic balance in stagnating flow area is the necessary dynamic condition of TM formation and abundant fine sediments are the other necessary condition of material source of TM. There is also topographical similarity between Yangshan Harbor area and the Yangtze estuary, with both having a semi-enclosed topography. Whether or not this topography restricts lateral exchange of suspended sediments and is helpful to TM formation, further studies need to be carried out. 3.3 Similarity in depositional characteristics of superficial sediments 3.4 Similarity in distributive characteristics of shoal bar 4 Significance of these similarities

关键词： Key words: Yangshan Harbor; Yangtze estuary; similarity; stagnating flow area; turbidity maximum; mouth bar