Hydrological Observation of Qiantang River in the River Crossing Tunnel of Metro Line 8

Hanyu Zhou1, Haiyang Dong2*, Hanzhang Lu3, Zongyu Li2, Fanjun Chen4

1Ocean Research Center OF Zhoushan, Zhejiang University, Zhoushan, Zhejiang Province, 310000, China
2Ocean College, Zhejiang University, Hangzhou, Zhejiang Province, 310058, China
3School of Management Engineering, Shandong Jianzhu University, Jinan, Shandong Province, 250101, China
4College of Architecture and Civil Engineering, Zhejiang University, Hangzhou, Zhejiang Province, 310058, China
*Corresponding author’s e-mail: ocean0458@163.com

Abstract. Observation on hydrological characteristics and sediment concentration were conducted in this research, and data analysis and summary were carried out on vertical tidal current flow and vertical sediment concentration. The hydrological and sediment environment of Qiantangjiang Metro Line 8 river-crossing channel was investigated.

1.Introduction
Qiantang River, which originates from Huangshan area in Anhui Province, flows through 14 cities into Hangzhou Bay. The flow section after Wenjiayan appears a tortuous appearance, also known as the ‘Zhi’ river. The Hangzhou Bay, which reduced from about 100km apart from south to north to 20 km, is like a huge horn. There is a huge ridge of sand bank in the longitudinal section of the riverbed, which rises upward on a slope of 1.5/10000 from Chapu to the top near the warehouse front, and then extends to Wenyan on an inverted slope of 0.6/10000. A sudden decrease of the riverbed capacity emerged since the riverbed has risen sharply from Mipu. When tides flow into the shallow riverbed, they are blocked, forming the world's miracle: Qiantang River Tide.

In order to meet the increasing traffic demand of Hangzhou City, the construction of Qiantang River Metro Tunnel across the river is implemented. In order to investigate the content of hydrology and sediment in the construction area Metro Line 6, field observation and analysis was conducted, which provides important information and solid basis for the design of the tunnel across the river.

2.The process and method of investigation

2.1. Methods
Two observation points, named DT81-1 and DT81-2, were selected on the tunnel line, where two vertical lines are arranged to measure the flow velocity, flow direction and sediment concentration in the large and medium tide for no less than 26 hours, respectively, and the corresponding tide level data are collected and provided.
Tidal current should be layered according the following rule: the depth is divided into 1 layer with flow depth below 2m, 2 layers for 2-5m depth, 3 layers for 5-8m depth, 5 layers for 8-11m depth, and 6 layers for 11m depth. The surface layer is 0.5m below flow surface while the bottom is 0.5m above the bottom\textsuperscript{[1]}.

| Points      | DT81-1            | DT81-2            |
|-------------|-------------------|-------------------|
| X Coordinate| 3354542           | 3349587           |
| Y Coordinate| 40538362          | 40523032          |
| Latitude    | 30°18′33″N        | 30°18′15″E        |
| Longitude   | 120°23′55″N       | 120°24′36″E       |

Table 1. Coordinate of observation points for hydrological test

For rivers affected by tidal currents, each observation period shall be no less than 100s, and each tidal observation shall last for no less than 26 hours. In the time when the flow direction is transferred, the current should be measured every 30 minutes\textsuperscript{[1,2]}.

The accumulated point method and the accumulated depth method were adopted for the suspended sediment sampling, which was carried out simultaneously with the fixed-point flow measurement. The sampling interval shall be less than 2 hrs. The concentration of suspended sediment sample should be obtained by weighing method, displacement method or photoelectric method.

2.2. Observation process

Local civil fishing boats were rent and engaged in this offshore survey. Four complete tidal periods of Qiantang River with length of 118 hours were selected. The tide level and other hydrological data of this two observation points are obtained continuously.

| Tidal type | Starting time | Ending time | Remarks                                      |
|------------|---------------|-------------|----------------------------------------------|
|            | Sonar calendar| Lunar calendar| Sonar calendar| Lunar calendar                             |
| Small tide | Dec.79:00     | Nov.9       | Dec.89:00 | Nov.10 | Sediment concentration observation once an hour, flow velocity and direction observation every 20mins |
| Median tide| Dec.89:00     | Nov.10      | Dec.108:00 | Nov.12 |
| Spring tide| Dec.108:00    | Nov.12      | Dec.127:00 | Nov.14 |

The tide level is observed by DCX-22 self contained pressure tide gauge made by Keller, Switzerland, with a recording interval of 1 minute. The tide level is observed and recorded synchronously with the process of flow velocity and direction measurement with ADCP.

Suspended sediment sampling shall be taken once an hour, and no sample shall be taken at the additional measuring point. The sampling period shall be synchronous with the flow measurement. At the same time of flow velocity and flow direction observation, suspension water samples are collected at each sampling vertical line of the cross section in the flow-stable period, which are respectively used for suspension sediment concentration and particle grading analysis.

Two boreholes were arranged for a depth of 30m each, and 60 samples in total were taken with one core per meter in the section of Qiantang River tunnel. The sediment characteristics of the core samples were analyzed to obtain the median particle size, grading and other sediment characteristics of the bottom bed drilling samples.
3. Results and analysis

3.1. Maximum velocity

The maximum velocity for rising and falling tide measuring points of each fixed vertical line is
counted according to the measured data, and the corresponding relative water depth is marked.

| Point number | Rising tide | Falling tide | Ratio |
|--------------|-------------|--------------|-------|
| DT81-1       | 2.0466      | 1.051        | 1.94  |
| DT81-2       | 1.568       | 1.294        | 1.21  |

b. Median tide

| Point number | Rising tide | Falling tide | Ratio |
|--------------|-------------|--------------|-------|
| DT81-1       | 1.193       | 0.465        | 2.56  |
| DT81-2       | 1.528       | 1.041        | 1.47  |

c. Neap tide

| Point number | Rising tide | Falling tide | Ratio |
|--------------|-------------|--------------|-------|
| DT81-1       | 0.579       | 0.379        | 1.53  |
| DT81-2       | 1.035       | 1.140        | 0.91  |

It can be concluded from the figure above that the maximum velocity in the rising and falling tide
period mostly appears on the surface of the vertical line, reflecting that the flow velocity decrease
from the upper part to the bottom. In the extreme velocity distribution, the maximum velocity of rising
tide is significantly higher than that of falling tide; the maximum velocity mainly appears in the upper
middle part of the water layer, concentrating in the surface layer.

3.2. Maximum velocity

The mean flow velocity were recorded and calculated, which are listed below. The direction of tide
flow are also shown in the chart.
Table 4. Average flow velocity and direction (m/s)

|                | Spring tide | Median tide | Neap tide |
|----------------|-------------|-------------|-----------|
| DT81-1         |             |             |           |
| Velocity (m/s)| 0.51        | 0.405       | 0.27      |
| Direction (°)  | 203         | 212         | 189       |
| DT81-2         |             |             |           |
| Velocity (m/s)| 0.56        | 0.43        | 0.23      |
| Direction (°)  | 196         | 204         | 195       |

b. Falling tide

|                | Spring tide | Median tide | Neap tide |
|----------------|-------------|-------------|-----------|
| DT81-1         |             |             |           |
| Velocity (m/s)| 0.35        | 0.26        | 0.22      |
| Direction (°)  | 75.3        | 96.6        | 86.8      |
| DT81-2         |             |             |           |
| Velocity (m/s)| 0.37        | 0.29        | 0.19      |
| Direction (°)  | 77.7        | 99.4        | 94.2      |

This area presents typical reciprocating flow characteristics in the distribution of the fixed vertical flow direction. From the flow velocity and direction of the two observation points, the tidal current in the Qiantang River estuary area has regular and obvious half-day cycle phenomenon with tidal cycle of about 12.5h. In terms of flow direction distribution, both the rising tide and the falling tide are strongly affected by the regional terrain, and the characteristic flow direction of the tide is significantly affected by the terrain.

3.3. Suspended sediment concentration

The average vertical sediment concentration is calculated as follows:

$$C_{sp} = \frac{\sum_{i=1}^{n} C_i \cdot C_{xi} \cdot V_{xi}}{10V_p}$$

When the flow velocity is relatively small and the flow direction is disordered, it may be unreasonable to calculate the average sediment concentration of the vertical line with the above velocity weighting formula, so the sediment concentration weighting calculation is used, as is shown below:

$$C_{sp} = \frac{\sum_{i=1}^{n} C_i \times C_{xi}}{\sum_{i=1}^{n} C_i}$$

Where $C_{sp}$ = mean suspended sediment concentration (kg/m$^3$)
$C_i =$weighting factors

$C_{ii} =$suspended sediment concentration($kg/m^3$)

$V_{ix} =$flow velocity of the observation point ($m/s$)

$V_p =$mean flow velocity of the river section ($m/s$)

The average value of sediment concentration of this two measuring points in the tide period is analyzed and counted in layers, as is shown in the table below:

Table 5. Mean suspended sediment concentration (mg/L)

|          | Rising tide | Falling tide |
|----------|-------------|--------------|
|          | Surfa ce    | 0.2H 0.4H 0.6H 0.8H Bottom tm | Surfa ce    | 0.2H 0.4H 0.6H 0.8H Bottom tm |
|          | Botto m     | Botto m/su face | Botto m     | Botto m/su face |
| DT81-1  | 347.8       | 335.2 513.6 600.7 900.4 001. 07 2.87 | 208.3       | 214.9 298.0 318.7 379.8 392.2 1.88 |
| 3        | 3           | 9       | 4     | 9     | 8  | 0       | 6         | 4  | 0         |
| DT81-2  | 312.2       | 345.1 344.7 371.6 671.9 196. 1.83 | 273.3       | 234.6 220.3 262.6 357.2 611.2 2.24 |
| 1        | 4           | 2       | 9     | 7     | 0  | 1       | 0         | 0  |

|          | Rising tide | Falling tide |
|----------|-------------|--------------|
|          | Surfa ce    | 0.2H 0.4H 0.6H 0.8H Bottom tm | Surfa ce    | 0.2H 0.4H 0.6H 0.8H Bottom tm |
|          | Botto m     | Botto m/su face | Botto m     | Botto m/su face |
| DT81-1  | 138.4       | 140.0 149.9 151.2 156.0 176.0 1.27 | 80.07       | 80.84 101.7 113.7 129.6 153.1 1.91 |
| 4        | 9           | 0       | 4     | 8     | 5  | 1       | 5         | 0  |
| DT81-2  | 68.19       | 70.34 76.99 96.99 133.2 132.1 1.94 | 88.26       | 86.49 84.59 109.9 116.1 155.5 1.76 |
| 3        | 7           | 3       | 6     | 1     | 0  | 2       | 7         | 7  |

|          | Rising tide | Falling tide |
|----------|-------------|--------------|
|          | Surfa ce    | 0.2H 0.4H 0.6H 0.8H Bottom tm | Surfa ce    | 0.2H 0.4H 0.6H 0.8H Bottom tm |
|          | Botto m     | Botto m/su face | Botto m     | Botto m/su face |
| DT81-1  | 61.96       | 85.92 104.4 96.25 94.58 99.68 1.61 | 60.34       | 80.14 90.54 91.77 101.8 116.4 1.92 |
| 5        | 3           | 3       | 6     | 1     | 0  | 3       | 9         | 3  |
| DT81-2  | 51.4        | 67.35 71.58 113.8 100.2 139.0 2.70 | 62.88       | 69.93 88.01 101.5 95.81 116.1 1.85 |
| 5        | 3           | 3       | 8     | 3     | 8  | 7       | 3         | 3  |

From the ratio of the average sediment concentration between the bottom layer and the surface layer, the ratio is all greater than 1 with the maximum value of 3.83 and the minimum value of 1.27, showing that the vertical distribution of sediment concentration gradually increase from the upper to the bottom layer. Most of the maximum value of sediment concentration appears in the bottom layer or 0.8H layer.

4. Conclusion
Observation on hydrological characteristics and sediment concentration were conducted in this research, and data analysis and summary were carried out on vertical tidal current flow and vertical sediment concentration. The hydrological and sediment environment of Qiantangjiang Metro Line 8 river-crossing channel was investigated.

In the rising and falling tide period, the maximum flow velocity of the fixed vertical line mostly appears on the surface of the vertical line, which to some extent shows that the flow velocity in the upper part of the area is faster and gradually slows down to the bottom. The average velocity in the falling tide is slightly less than that in the rising tide period. The characteristic flow direction of the tide is significantly affected by the topography. The velocity of spring tide is significantly higher than that of middle tide and neap tide.
The sediment concentration increases with flow depth, and the maximum sediment concentration appears in the bottom layer. The sediment concentration in spring tide is higher than that in middle and low tide.

More tests on hydrogeological and sediment environment need to be performed at Qiantang river channel to further verify the geological bearing capacity.

Acknowledgments
This research was financially supported by the Science and Technology Program Project of ZhouShan City of China (No.2020C41064).

References
[1] National basic scale map scheme of the people's Republic of China Part 1: 1:500 1:1000 1:2000 topographic map scheme (GB / T 20257.1-2007).
[2] Surveying and mapping industry standard of the people's Republic of China: safety code for surveying and mapping operators (CH 1016-2008).
[3] Q. Zhu, B.C. van Prooijen, Z.B. Wang et al., Bed-level changes on intertidal wetland in response to waves and tides: A case study from the Yangtze River Delta[J]. Marine Geology, 2017, 385.
[4] Davies-Vollum, K.S. and M. West, Shoreline change and sea level rise at the Muni-Pomadze coastal wetland (Ramsar site), Ghana. Journal of Coastal Conservation, 2015, 19(4): p. 515-525.
[5] Kengo Sunada. On a collaborative field observation synchronized with the spaceborne and airborne remote sensing for understanding the hydrological cycle “The Biwako Project”[J]. Japan Society of Civil Engineers,1994,2.
[6] Sea surface salinity estimates from spaceborne L-band radiometers: An overview of the first decade of observation (2010–2019)[J]. N. Reul, S.A. Grodsky, M. Arias, J. Boutin, R. Catany, B. Chapron, F. D’Amico, E. Dinnat, C. Donlon, A. Fore, S. Fournier, S. Guimbard, A. Hasson, N. Koledziejczyk, G. Lagerloef, T. Lee, D.M. Le Vine, E. Lindstrom, C. Maes, S. Mecklenburg, T. Meissner, E. Olmedo, R. Sabia, J. Tenerelli, C. Thouvenin-Masson, A. Turiel, J.L. Vergely, N. Vinogradova, F. Wentz, S. Yueh. Remote Sensing of Environment.
[7] María Julieta Galliari, Carolina Tanjal, María del Pilar Alvarez et al. Hydrochemical dynamics of a wetland and coastal lagoon associated to the outer limit of the Rio de la Plata estuary[J] Continental Shelf Research, 2020, 200