Calibration of Midstream Buoy Coefficient Based on Flow Measurement

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Abstract: The midstream float method is a standby flow measurement method adopted by hydrological stations when the river floods are rising and falling sharply and the flow meter is difficult to measure or special water regime occurs. In this paper, based on the Years of measured flow data of Xiaolongtan Hydrological Station of Nanpanjiang River, the Midstream Buoy Coefficient in the natural river course of Nanpanjiang River Basin is calculated and analyzed. The average buoy coefficient is calculated by measuring the actual flow divided by the imaginary flow and the average value is 0.76 and the maximum variation is less than 14\%. This method can solve the actual needs of high flow measurement. The results can provide technical basis for sudden flood, special water regime, emergency monitoring, flood prevention and early warning. The flow measurement under the condition of insufficient testing personnel.

1. Instruction
Flow measurement is one of the most basic and important tasks in hydrological measurement. At present, Xiaolongtan Station has formed a pattern that is mainly based on cable flow measurement and supplemented by other flow measurement methods. Many measurement methods have their limitations because of the complexity of the hydrological characteristics of natural rivers. Flow measurement by buoy method is unstable due to the use of buoy coefficients and borrowed sections. However, conventional measuring facilities such as velocity meter are often difficult to measure when abnormal floods coming. Flow measurement by buoy method is still the flood measurement method of Xiaolongtan Station because of its characteristics that have easy material selection, low cost, easy operation, fast flow measurement speed and good safety performance. A large number of comparative tests have been carried out to analyze the variation law of buoy coefficients in order to improve the accuracy of buoy flow measurement. It provides a basis for improving the accuracy of flood flow measurement.

2. Watershed Area
Xiaolongtan Hydrological Station was set up by Yunnan Hydrological General Station in April 1960. It was moved downstream 500 m because of the collapse of the basic section in June 1967. It was
renamed Xiaolongtan (Ⅱ) Station. This station is located at the foot of Xiaolongtan Mountain, Kaiyuan, Yunnan Province.

The purpose of the station is to collect the basic hydrological information of the main stream of Nanpan River. It provides hydrological information including the water quantity, water quality and other factors which can improve the development and utilization of water resources downstream. At the same time, it also serves for flood control and drought relief in downstream areas. It is the important national hydrological station and the national water quality monitoring station. The stations are Nanpanjiang mainstream control station. The monitoring items include precipitation, water temperature, bank temperature, water level, flow, suspended sediment transport rate and sediment concentration in single sample, undertake surface water quality sampling, water information flood, hydrological forecast and other monitoring tasks.

Since the construction of the station, the highest water level is 1046.69m (August 18, 1971), the lowest water level is 1036.57m (March 22, 2007), and the average annual water level is 1038.00m. The maximum flow rate is 2220 m³/s (August 18, 1971), the minimum flow rate is 3.90 m³/s (May 14, 1982), and the annual average flow rate is 126 m³/s. The annual maximum precipitation is 1140.4 mm (1968), the minimum precipitation is 542.0 mm (1992), and the annual average precipitation is 832.5 mm. The flood lasted 11.0-89.3 hours, the peak duration was 1.0-13 hours, and the warning water level was 1042.95 m.

3. Calibration of Midstream Buoy Coefficient

The midstream buoy coefficient is a very difficult flow measurement method. Generally speaking, it is required to measure the river with stable location and relatively concentrated midstream velocity. The buoy section coincides with the flow measurement section. The shape of the section is U-shaped. The upper section is 70 m upstream of the basic water gauge section. The lower section is 70 m upstream of the flow measurement section. The distance between the upper and lower sections of the buoy section is 70 m. The width of the water surface is about 51.2-105.2 m. There is no diversion or stagnant water in the section. The test of the river is fairly straight. There is a coal-carrying bridge at 100m upstream and 200m downstream of the section. A fork ditch is added at 100m downstream, with factory waste and sludge. The river regime is stable and meets the condition of mid-harvest flow measurement. According to the principle of flow measurement by midstream buoy coefficient, it is the main factor affecting the accuracy of flow measurement. Therefore, the factors affecting the buoy coefficient are analyzed in detail in this paper. Furthermore, the buoy coefficient of the station is proposed.

3.1 Analysis Method

According to the principle of relative motion of buoy in water flow. Taking into account the main factors affecting the operation of buoys, the semi-theoretical and semi-empirical formulas shown in Formula (1) are mostly adopted.

\[ K_f = K_1(1 + AK_v) \]  \hspace{1cm} (1)

- \( K_f \) — Medium buoy coefficient;
- \( K_1 \) — Average surface velocity coefficient of cross section;
- \( K_v \) — Average cross-section air drag coefficient.

Above all factors, the resistance coefficient \( A \) of buoy is mainly related to the type of buoy, the buoy of the station adopts natural buoys with similar shape and material, so the value can be regarded as a constant value.

The cross-section average surface velocity coefficient \( K_1 \) is a comprehensive coefficient with many influencing factors. In the stations with regular water flow, the variation rate of \( K_1 \) is small and can be approximated as a constant. As mentioned above, the test section of Xiaolongtan Station is straight and stable, so the change rate of \( K_1 \) value is not large.
In all, the A and $K_1$ values of the station are relatively stable and the values mainly change with the wind direction and wind force at different times. Wind direction and wind force are the main factors affecting the error of buoy coefficients. It is difficult to quantify them from the causes because of their complex influence factors. This paper uses the comparative measurement method to analyze them according to the requirements of the code. So the flow rate is measured simultaneously by the cable flow meter and the midstream buoy method. The measured cross-section flow rate is divided by the imaginary flow rate to calculate its value and then its analysis is carried out.

According to the test of buoy coefficients stipulated in the Standard for Flow Measurement of Rivers (GB 50179-2015), the stations that have the condition of comparative test should carry out comparative test with the current meter method and the buoy method \[2-3\] . The buoy coefficients can be determined by the water level-flow relationship curve method and the surface velocity coefficient method in the stations of unconditional comparative test. The buoy coefficient shall be divided by the section flow rate by the section virtual flow rate or by the section average velocity by the section virtual flow rate \[4-5\] . Flow measurement by midstream buoy method requires that 3～5 buoys should be placed in mid-flood area. The buoys are adjacent to each other and operate normally. The difference between the longest and shortest operation duration should not exceed 10% of the shortest operation duration. There should be 2～3 buoys. So the maximum velocity of the main stream should be measured by the method of midstream buoy. According to the section map and the lateral distribution map of the river section measured by the station, the maximum velocity of the main stream should be measured. It is determined that the high-water part of the station is located at the starting point of 40.0m～65.0m, the middle water part is located at the starting point of 45.0m～70.0m, and the low water part is located at the starting point of 35.0m～55.0m. This comparative survey was completed in the main flood season of 2014. A total of 33 sets of experimental data were obtained. The experiment was mainly carried out at the middle and high-water levels. The experimental data are shown in Table 1.

Table1. Statistics of experimental data of Flow rate measured by anemometer at Xiaolongtan Station

| Serial number | Water level | Buoy virtual flow | Flow rate measured by anemometer | Flow rate measured by anemometer | Serial number | Water level | Buoy virtual flow | Flow rate measured by anemometer | Flow rate measured by anemometer |
|---------------|-------------|-------------------|----------------------------------|----------------------------------|---------------|-------------|-------------------|----------------------------------|----------------------------------|
| 1             | 1038.99     | 319               | 276                              | 0.87                             | 18            | 1040.10     | 596               | 451                              | 0.76                             |
| 2             | 1037.99     | 174               | 126                              | 0.72                             | 19            | 1040.32     | 679               | 495                              | 0.73                             |
| 3             | 1039.53     | 454               | 344                              | 0.76                             | 20            | 1039.51     | 404               | 341                              | 0.84                             |
| 4             | 1039.76     | 514               | 386                              | 0.75                             | 21            | 1038.70     | 292               | 219                              | 0.75                             |
| 5             | 1039.86     | 560               | 404                              | 0.72                             | 22            | 1039.65     | 468               | 366                              | 0.78                             |
| 6             | 1038.76     | 312               | 227                              | 0.73                             | 23            | 1040.02     | 566               | 435                              | 0.77                             |
| 7             | 1038.64     | 286               | 211                              | 0.74                             | 24            | 1040.26     | 645               | 483                              | 0.75                             |
| 8             | 1039.48     | 410               | 336                              | 0.82                             | 25            | 1041.00     | 883               | 631                              | 0.71                             |
| 9             | 1039.46     | 437               | 332                              | 0.76                             | 26            | 1041.59     | 1120              | 749                              | 0.67                             |
| 10            | 1039.55     | 455               | 348                              | 0.76                             | 27            | 1041.62     | 1050              | 755                              | 0.72                             |
| 11            | 1039.79     | 517               | 391                              | 0.76                             | 28            | 1042.37     | 1240              | 919                              | 0.74                             |
| 12            | 1039.89     | 540               | 409                              | 0.76                             | 29            | 1042.93     | 1520              | 1060                             | 0.70                             |
| 13            | 1039.74     | 488               | 382                              | 0.78                             | 30            | 1040.23     | 609               | 477                              | 0.78                             |
3.2 Calibration of Midstream Buoy Coefficient

The midstream buoy system is the rate of the actual flow measured by the same water level velocimeter method and the actual virtual flow measured by the buoy method. The calculation of the virtual flow of the buoy is shown in Formula (2).

\[ Q_v = A_m \cdot v_m \]  

\( Q_v \) —— virtual flow of cross-section;  
\( A_m \) —— Sectional area;  
\( v_m \) —— Flow velocity of midstream buoy.

The calculation of the measured flow rate of the anemometer is shown in Formula (3).

\[ Q_s = A_m \cdot v \]  

\( Q_s \) —— The flow rate is measured by the flow meter method.  
\( A_m \) —— Section area;  
\( v \) —— The average velocity of cross-section was measured by flow meter method.

3.3 Buoy Coefficient Calibration

Thirty-three experimental data obtained in this experiment were calculated by arithmetic average method and correlation method respectively.

The results of arithmetic average method are shown in Table 1. As can be seen from Table 1, the maximum value of the single buoy coefficient is 0.87, the minimum is 0.67, the mean value is 0.76, and its variation is less than 14%.

The correlation between the measured flow rate of the anemometer and the virtual flow rate of the same mid-flood buoy is established by plotting the measured flow rate of the anemometer (m³/s) as the ordinate and the virtual flow rate of the midstream buoy (m³/s) as the abscissa (Figure 1). As can be seen from figure 2, the point data are densely banded, and the correlation equation is \( Q_{\text{cross-section}} = 0.7575Q_{\text{buoy}} \), the correlation coefficient is 0.9832. The above analysis results show that the influence of wind on buoy is not obvious or constant, so the influence of air resistance on buoy coefficient can be neglected. The coefficient of the buoy in Xiaolongtan Hydrological Station is determined to be 0.76.
Figure 1. The relationship between measured flow rate and virtual flow rate of anemometer

4. Conclusion
(1) Xiaolongtan Hydrological Station is a large river control station which is often accompanied by high velocity and floating matter during flood season. Conventional testing methods are difficult to measure. According to the river characteristics of the station, the midstream buoy method is selected for high flood test.

(2) The analysis of the station's test data shows that the buoy system fluctuates is 0.76 up and down. Its maximum variation is less than 14%. This shows that the main factor affecting the buoy coefficient is wind speed which has no obvious influence on it or the influence is relatively constant. Therefore, the use of midstream buoy method in the station can ensure the accuracy of high-water measurement.

(3) In this experiment, the influencing factors are generalized and analyzed but the causes can not be deeply analyzed. It needs to be further analyzed in the future work practice to improve the accuracy of buoy flow measurement.

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