Analysis of influencing factors on the discharge parameters of irrigation canal in Zhejiang province

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Abstract. Water measurement through standard cross-section is one of the main methods of water measuring of irrigation canal. This paper takes Zhejiang Province as an example, and calibrates 16 canal standard cross-sections of 5 irrigation areas, and uses the curve of water level-discharge relation and the power function formula to fit coefficient "K" and index "u", and applies the linear regression method to analyze the influence of canal width, slope and lining type on the flow parameters. The results show that the coefficient "K" of canal standard cross-section range from 0.6986 to 4.7035, and the index "u" range from 1.3334 to 2.6376. The discharge parameters are positively correlated with canal width and slope, and are negatively correlated with canal roughness.

1. Introduction
The relationship between water level and discharge in canal section is an important basis for flow estimation. Canal section is generally made of concrete casting or masonry lining. The boundary conditions are relatively consistent and the shape of the section is similar. It belongs to the steady flow with gradual change. The relationship between water level and discharge of most canal sections is relatively stable, and presents a single parabolic shape. Liu Wei et al. studied a method of estimating flow by using stable cross-section water level-discharge relationship, and the analysis showed it has the advantages of simple observation, accurate application, labor-saving and time-saving, had become one of the commonly used methods of water measurement in irrigation area[1]. Li Xiaoyu et al. studied the application of Excel in the test of water level discharge relation curve, and the analysis showed using ECXEL to test three kinds of water level discharge relation curve makes the calculation more convenient and the result more accurate and scientific[2]. Wang Anqiang studied the calibration method of water level-discharge relation curve of canal section, and the method had been applied in some irrigation areas of Xinjiang Uygur Autonomous Region and achieved good results [3]. The power function formula of canal discharge is formed by fitting the stable relationship between water level and discharge of monitoring section, and the coefficient “K” and index “u” are determined. They are the basic support for automatic monitoring of water level to discharge. Based on the calibration data of 16 water measuring facilities of canal standard cross-section of 5 irrigation areas in Zhejiang Province, this paper analyzed the influence of canal width, slope and lining type on the fitting coefficient “K” and index “u”, which provided the important guidance for water measuring of irrigation area in Zhejiang Province even southern China.

2. Data and methods
2.1. General situation of study area

Figure 1 is the geographical location map of Zhejiang Province. Zhejiang Province is located in southeastern China and on the southern wing of the Yangtze River Delta, between east longitude 118°01'~123°10' and north latitude 27°02'~31°11'. Its land area is 101,800 km², mainly mountains and hills. Its sea area is vast, and the total length of the coastline is 6,486 km, ranking first in China. Zhejiang Province belongs to the subtropical monsoon climate zone, with an average annual temperature of 15-18°C and an average annual rainfall of 980-2,000 mm. Its effective irrigation area is 1.44 million ha, and the total number of irrigation areas is more than 35,000.

![Geographical location map of Zhejiang Province.](image)

2.2. Data

The research is based on the water level and discharge data from 2016 to 2018 of 16 national irrigation water metering stations of 5 irrigation areas in Zhejiang Province. Information of the stations in Table 1 are from Water Resources Management System of Zhejiang Province. Most of the data are obtained from actual measurements, and few data are provided by the irrigation area administrations.

Table 1. Information for the national irrigation water metering stations used in this study.

| Number | Station Name                                      | Station code   | Length of record | Latitude (°N) | Longitude (°E) |
|--------|---------------------------------------------------|----------------|------------------|---------------|----------------|
| 1      | Water intake of the East Trunk Canal              | 3308810001     | 2016~2018        | 118.533       | 28.473         |
| 2      | Water diversion of the East Branch Canal          | 3308810002     | 2016~2018        | 118.532       | 28.535         |
| 3      | Water intake of the Jiantounong Hydropower Station| 3308810003     | 2016~2018        | 118.518       | 28.459         |
| 4      | Water intake of the Qingkou Pumping Station      | 3308810007     | 2016~2018        | 118.458       | 28.572         |
| 5      | Water intake of the Barrage in Fenglin Town       | 3308810015     | 2016~2018        | 118.497       | 28.502         |
| 6      | Water diversion of the East Trunk Canal in Fenglin Town | 3308810016 | 2016~2018        | 118.499       | 28.513         |
| 7      | Water diversion of the East Trunk Canal of Lianjianong Reservoir | 3308810020 | 2016~2018        | 118.581       | 28.567         |
| Water Diversion/Intake | Code          | Year       | Water Level | Discharge |
|------------------------|---------------|------------|-------------|-----------|
| 8 Water diversion of the East Trunk Canal in Hecun Town | 3308810021    | 2016–2018  | 118.550     | 28.629    |
| 9 Water intake of Tangbeilong Reservoir          | 3308810024    | 2016–2018  | 118.583     | 28.561    |
| 10 Water diversion of the 72 Trunk Canal          | 3307260005    | 2016–2018  | 119.848     | 29.451    |
| 11 Water diversion of the Dilong Branch Canal     | 3308810011    | 2016–2018  | 118.524     | 28.705    |
| 12 Water diversion of the Wutongyuan West Trunk Canal | 3311240019   | 2016–2018  | 119.402     | 28.570    |
| 13 Water intake of Yangliufeng Reservoir          | 3308810013    | 2016–2018  | 118.651     | 28.731    |
| 14 Water intake of the Wutongyuan West Trunk Canal | 3311240002   | 2016–2018  | 119.405     | 28.569    |
| 15 Water intake of the Zhongcun Branch Canal       | 3305230003    | 2016–2018  | 119.526     | 30.636    |
| 16 Water intake of the Huangfen Trunk Canal        | 3307840004    | 2016–2018  | 120.041     | 28.990    |

2.3. Methods

2.3.1. Calculation principle of water level-discharge relation in canal. Whether the relationship between water level and discharge at canal section is stable or not depends mainly on the hydraulic factors affecting the discharge, which can be explained by Manning's formula [4].

\[
V = \frac{1}{n} R^{\frac{1}{2}} i^{\frac{1}{2}}
\]

\[
Q = AV = \frac{1}{n} R^{\frac{1}{2}} i^{\frac{1}{2}} A
\]

Where \(Q\) is discharge, m\(^3\)/s; \(V\) is average flow velocity, m/s; \(A\) is discharge area, m\(^2\); \(n\) is roughness of canal bed; \(R\) is hydraulic radius; \(i\) is gradient.

Taking rectangular canal standard cross-section as an example:

\[
A = B \times H
\]

\[
R = \frac{\omega}{\frac{B}{A}} = \frac{B+2H}{B\times H}
\]

Where \(B\) is canal width, m; \(H\) is water depth, m; \(\omega\) is wetted perimeter, m.

2.3.2. The fitting function of water level-discharge relation of Canal Standard Cross-section. According to the principle of water level-discharge relationship, the formula of water measuring for canal cross-standard section should be expressed by power function [5].

\[
Q = KH^u
\]

Where \(Q\) is discharge, m\(^3\)/s; \(H\) is water depth, m; \(K\) is the fitting coefficient; \(u\) is the fitting index.

According to the observed data of water level and discharge in canal standard cross-section, the regression analysis method can be used to fit the discharge coefficient and index, and the power function of water level and discharge can be established.

3. Results and discussion

Based on the calibration data of 16 canal standard cross-sections in Wanyao Irrigation Area, Tongjiqiao Irrigation Area, Jiangbei Irrigation Area, Fushi Irrigation Area and Yangxi Irrigation Area
in Zhejiang Province, the relationship curve of water level and discharge is established, the discharge coefficient “$K$” and index “$u$” are fitted, and the power function formula is formed. The influence of canal width, slope and lining type on discharge coefficient “$K$” and index “$u$” is analyzed by selecting different types of canal standard cross-sections.

3.1. Effect of canal width on the discharge parameters

Table 2 is the discharge parameters of canals with different widths. Based on the calibration data of 9 canal standard cross-sections of Wanyao Irrigation Area in Zhejiang Province, the effect of canal width on the discharge parameters is analyzed. On the premise that slope, roughness and construction technology are basically the same, the comparison shows that the discharge coefficient “$K$” and index “$u$” are generally on the rise with the increase of canal width, and the slopes of the change trend lines are more than 0 ($k_1=0.5687$, $k_2=0.2706$). As shown in Figure 2, the discharge parameters of canal standard cross-section are positively correlated with the canal width.

**Table 2. The discharge parameters of canals with different widths.**

| Number | Station Name                                | canal width | Discharge Parameter Coefficient “$K$” | Index “$u$” |
|--------|---------------------------------------------|-------------|---------------------------------------|-------------|
| 1      | Water intake of the East Trunk Canal        | 5.2         | 3.4544                                | 2.4351      |
| 2      | Water diversion of the East Branch Canal    | 4.8         | 3.0634                                | 2.3206      |
| 3      | Water intake of the Jiantounong Hydropower Station | 6.3         | 3.8671                                | 2.6376      |
| 4      | Water intake of the Qingkou Pumping Station | 0.8         | 0.6986                                | 1.1572      |
| 5      | Water intake of the Barrage in Fenglin Town | 2.2         | 1.4892                                | 1.4812      |
| 6      | Water diversion of the East Trunk Canal in Fenglin Town | 1.8         | 1.3958                                | 1.5966      |
| 7      | Water diversion of the East Trunk Canal of Lianjianong Reservoir | 3.5         | 2.6960                                | 1.9245      |
| 8      | Water diversion of the East Trunk Canal in Hecun Town | 3           | 2.3723                                | 2.0987      |
| 9      | Water intake of Tangbeilong Reservoir       | 1.4         | 1.3832                                | 1.3334      |

![Figure 2. The change trends of the discharge parameters with different widths](image)

(a) $y = 0.5687x + 0.4364$  $R^2 = 0.9717$

(b) $y = 0.2706x + 1.0153$  $R^2 = 0.9464$
3.2. Effect of canal slope on the discharge parameters

Table 3 shows the discharge parameters with different slopes. Based on the calibration data of three stations, the effect of canal slope on the discharge parameters is analyzed. On the premise that width, roughness and construction technology are basically the same, the comparison shows that the discharge coefficient “K” and index “u” are generally on the rise with the increase of canal slope, and the slopes of the change trend lines are more than 0 (k1=13.466, k2=6.8297). As shown in Figure 3, the discharge parameters of canal standard cross-section are positively correlated with the canal slope.

Table 3. The discharge parameters with different slopes.

| Number | Station Name                               | Canal Slope (‰) | Discharge Parameter |
|--------|--------------------------------------------|------------------|--------------------|
|        |                                            |                  | Coefficient “K”    |
| 1      | Water diversion of the 72 Trunk Canal       | 0.4              | 1.8888             |
| 2      | Water diversion of the Dilong Branch Canal  | 0.37             | 1.2671             |
| 3      | Water diversion of the Wutongyuan West Trunk Canal | 0.33          | 0.9264             |
|        |                                            |                  | Index “u”          |
|        |                                            |                  | 1.9909             |
|        |                                            |                  | 1.6472             |
|        |                                            |                  | 1.5002             |

(a) ![Graph](image1.png)  (b) ![Graph](image2.png)

Figure 3. The change trends of the flow parameters with different slopes (a: coefficient “K”; b: index “u”).

3.3. Effect of canal roughness on the discharge parameters

Table 4 is the discharge parameters with different roughness. Based on the calibration data of four stations (water intake of Yangliufeng reservoir, water intake of the Wutongyuan west trunk canal, water intake of the Zhongcun branch canal and water intake of the Huangfen trunk), the effect of canal lining type on the discharge parameters is analyzed. On the premise that width, slope and construction technology are basically the same, the comparison shows that the discharge coefficient “K” and index “u” are generally on the decrease with the increase of canal roughness, and the slopes of the change trend lines are less than 0 (k1=-325.1, k2=-80.672). As shown in Figure 4, the discharge parameters of canal standard cross-section are negatively correlated with the canal roughness.

Table 4. The discharge parameters with different roughness.

| Number | Station Name                               | Lining type    | Roughness | Discharge Parameter |
|--------|--------------------------------------------|----------------|-----------|--------------------|
|        |                                            | concrete       | 0.017     | Coefficient “K”    |
| 1      | Water intake of Yangliufeng Reservoir      |                | 4.7035    | Index “u”          |
|        |                                            |                |           | 2.5251             |
2 Water intake of the Wutongyuan West Trunk Canal masonry 0.022 4.1884 1.7644
3 Water intake of the Zhongcun Branch Canal dry-stone 0.025 1.5597 1.5205
4 Water intake of the Huangfen Trunk Canal earth canal 0.030 0.8588 1.4768

Figure 4. The change trends of the fitting parameters with different roughness (a: coefficient "K"; b: index “u”).

4. Conclusion
The discharge parameters of canal standard cross-section are positively correlated with the canal width, and the discharge coefficient “K” and index “u” are generally on the rise with the increase of canal width.

The discharge parameters of canal standard cross-section are positively correlated with the canal slope, and the discharge coefficient “K” and index “u” are generally on the rise with the increase of canal slope.

The discharge parameters of canal standard cross-section are negatively correlated with the canal roughness, and the discharge coefficient “K” and index “u” are generally on the decrease with the increase of canal roughness.

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