

# Ecological cross section rehabilitation in Fenghui Main Canal

T Y Fang<sup>1</sup>, H T Liu<sup>2</sup>, X D Liu<sup>1</sup>, X L He<sup>1</sup>, J Chen<sup>3,4</sup> and Y Han<sup>1,4</sup>

<sup>1</sup>College of Water Resources & Civil Engineering, China Agricultural University, 17 Tsinghua East Rd., Haidian District, Beijing 100083, China

<sup>2</sup>College of Water and Environmental Engineering, Changchun Institute of Technology, Changchun, 130012, China

<sup>3</sup>College of Engineering, China Agricultural University, 17 Tsinghua East Rd., Haidian District, Beijing 100083, China

E-mail: jchen@cau.edu.cn/yhan@cau.edu.cn

**Abstract.** In order to rehabilitate the optimal cross section of the Fenghui main canal, this paper developed some ecological rehabilitation plans based on the original canal cross section and the vegetation is arranged in both boundary and bottom of channel. The physical model test was carried out to study resistance parameters for flow over vegetation. By analyzing the value of section mean roughness under different design schemes, the energy loss and cost corresponding to each reconstruction scheme can be compared. The results show that: based on momentum balance principle and improved hydraulic radius model, the theoretical value and measurements from load cell are quite similar. Meanwhile, the optimal vegetation lay-out in cross section based on smallest energy loss and best hydraulic characteristics can be determined. From the perspective of project cost analysis, it is recommended to select the cross-pavement ecological vegetation scheme from the aspects of hydraulic characteristics and economics.

## 1. Introduction

The Fenghui Irrigation District is a medium-sized irrigation area as one of eight famous irrigation districts in Shannxi province, which also combines both drainage and ecological benefits. Fenghui main canal is constructed by the traditional concrete and normally contains three smooth boundary which have serious impact on the ecological environment. It causes the deterioration of environmental conditions, biodiversity loss, severe agricultural pollution and decreased self-purification capacity problems increasingly [1]. Thus, the renovation of main canal has become a hot issue. Irrigation district canals' function has gradually combined water delivery and ecological landscape, and they are designed with new concepts such as return to nature, restoration of ecology, and natural harmony [2]. The ecological vegetation recovered in Gaoyou Irrigation District canals enriches the biodiversity of the canal system, rebuild the ecological self-purification capability, and achieves the double effects of water conservation and ecological protection [3]. The Handun Irrigation District was facing many problems throughout the development of the past a few decades, which include that the ecological environment was destroyed, the ecological condition was degraded, and the natural resources were wasted. After the construction of the ecological irrigation district, we can rebuild the water landscape and water ecological culture, so as to utilize the water resources efficiently [4]. However, the construction of ecological irrigation areas in China also faces many problems, such as low efficiency



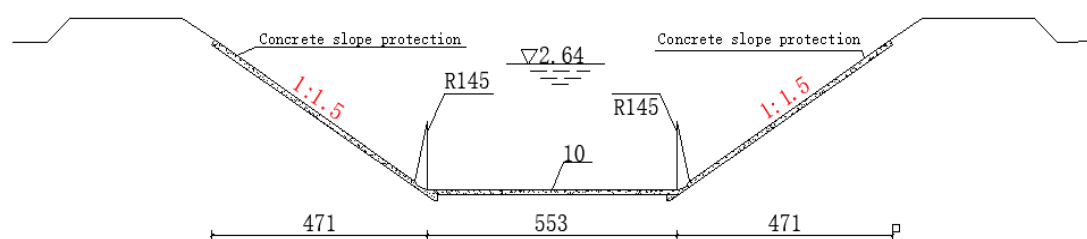
of water-saving irrigation, large waste of water resources, impact on the biodiversity of irrigation areas, serious pollution in irrigation areas, low production efficiency [5,6] and especially the research on the ecological problems of irrigation canals are still infancy. The complete theoretical system has not been formed yet and the ditches' ecological rehabilitation technology needs to be gradually improved [7].

In the design of ecological channels, flow over vegetation will affect the flow pattern and increase the resistance of the channels. Therefore, the calculation of the vegetation resistance in the channels is of the highest priority. There are two research methods for determining the flow resistance in ecological channels. One is to obtain the resistance characteristics of the vegetation through stress analysis of the vegetation, and the other is to increase the roughness coefficient that represents the mean roughness of the river channel (such as Manning's coefficient, Darcy Weisbach's coefficient and chezy's coefficient) [8]. Wilson and Horritt [9] calculated the roughness coefficient of submerged aquatic plants in the channel and pointed out that the Manning coefficient is no longer a constant, but is closely related to the depth of water. The results show that there is a linear relationship between the drag force and the mean flow velocity of the section. Tang *et al* [10] proposed the concept of a series of equivalent hydraulic parameters for the first time and established a formula for calculating the equivalent Manning roughness coefficient and the additional Manning coefficient of the equivalent plant. Green [11] determined the vegetation resistance parameters of more than 300 wild rivers through experiments, and conducted the regression analysis of vegetation resistance parameters and vegetation resistance to obtain an empirical model. The results of this study gave the relationship between the proportion of cross-sectional area occupied by plants and the drag coefficient. It can be seen that the interaction mechanism between vegetation and water flow in ecological channels is very complicated, and the design of most ecological channels is the result of empirical or semi-empirical design [12].

Based on the research of rehabilitation in Fenghui main canal, this paper proposes an optimal method of laying the vegetation on the bank and bottom of the canal, and develops experiments to determine the flow resistance of vegetation patch in a channel. By calculating the section mean roughness value under different design schemes, and comparing the energy loss and cost corresponding to the different ecological channel reconstruction schemes, we find the optimal rehabilitation plan of Fenghui main canal.

## 2. The basic data of irrigation district and ecological canal section rehabilitation

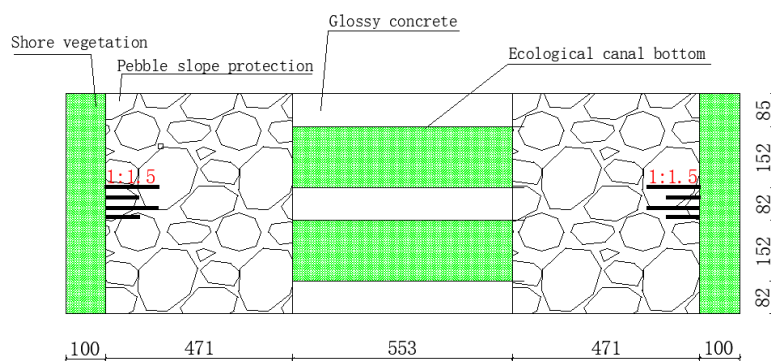
At present, the cross section of the main channel adopts a trapezoidal section with an arc-shaped slope (figure 1), and the bottom of the channel adopts a C<sub>20</sub> concrete lining with a lining thickness of 0.10 m. The channel has an upstream batter ratio of 1:1.5 and is constructed of cast-in-place C<sub>20</sub> concrete to above 0.5 m of the design water level, the thickness of the building is 0.10m. The design has a vertical drop of 0.25‰ and a design flow of 11 m<sup>3</sup>/s.



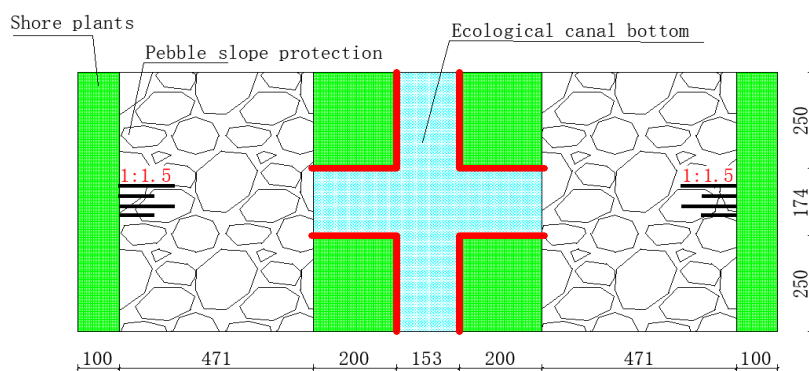
**Figure 1.** Schematic diagram of the Fenghui channels main canal.

Considering that the terrain around the Fenghui Irrigation District is universal and there are not many mountains and rocks, it is not appropriate to use rocks to protect slopes. According to the economic principle, we use pebble slope protection and vegetation along the shore. Three-dimensional geotextile mat technology is used to tile along the bottom of the channel, which could provide space

for the growth of plants. In this way the plants, net mats, and roots can be combined with the soil smoothly to form an ecological section firmly attached to the bottom of the canal. Overall, there are three types of ecological vegetation arrangements shown as the horizontal layout (figure 2), full and cross laying (figure 3).

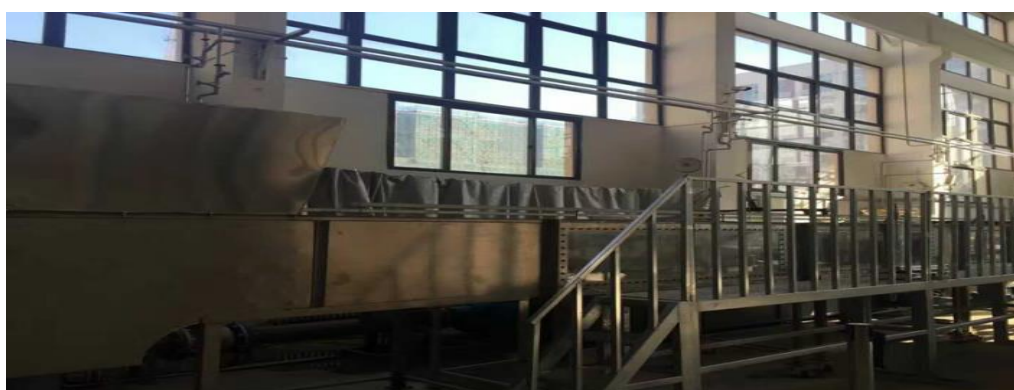


**Figure 2.** Horizontal laying of vegetation at the bottom of the ecological channel section.



**Figure 3.** Full and Cross laying of vegetation at the bottom of the ecological channel section.

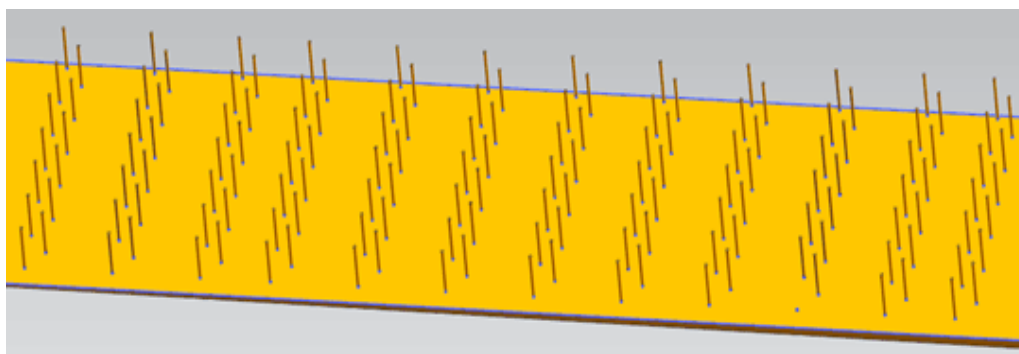
### 3. Determination of resistance parameters in ecological channels



**Figure 4.** Circulating water channel.

The rehabilitation of the ecological section requires to arrange the vegetation at the bottom of the channel. After the arrangement of the patch vegetation, it is necessary to calculate the impact on the flow capacity of the overall channel. In view of the fact that there is no universal model for the

resistance of the flow over the patch ecological vegetation. So a model experiment conducted in the circulation tank at China Agricultural University (figure 4) is used to determine the resistance for the flow conditions of the vegetation. The cylinders ( $d=0.005$  m,  $h=0.3$  m) are used to simulate vegetation (figure 5). Considering that eco-vegetation usually exists in the form of strips in ecological channels, the patch-like arrangement of vegetation is used in this experiment, and multiple rows of lateral vegetation are studied as a patch. The test layout is shown in the figure below:



**Figure 5.** The way of laying the bottom of the canal with acrylic rods

Based on the principle of mechanical balance and the improved hydraulic radius model, the formulas for calculating the shear force of the vegetation channel are shown as:

$$\tau = \rho g R i \quad (1)$$

where  $\rho$  = the density of water in  $\text{kg/m}^3$ ,  $g$  = gravitational acceleration.  $R = V / A$ ,  $R$  = the hydraulic radius, the unit is m,  $V$  = the volume of the vortex =  $b \times h \times L$ ,  $b$  = the channel width,  $L$  = the full development length of the vortex,  $A$  = the sum of the wall areas in contact with the water flow,  $i$  = the slope of the canal, which is 0.0022. Total resistance can be calculated as:

$$F = \tau A = \rho g V i \quad (2)$$

The ADV was used to measure the velocity distribution of each vegetation belt in order to quantify the volume of the vortex, and the resistance can be calculated based on the vortex volume behind the vegetation. To verify the rationality of formula (1), the vegetation resistance in the experiment was directly obtained with a load cell, so the reliability of model (2) can be verified by comparing the calculated and measured values. In this experiment, the vegetation use two rows,  $V=b \times h \times L \times 2$ , table 1 shows the calculated value  $F$  of the resistance at the average flow velocity  $U$  under different sections. At the same time, load cell was used to measure the drag force of the vegetation and compared with the calculated values. The measured value was close to the calculated value and the average error was 8%. Therefore, the resistance can be directly calculated by the formula (2) in the channel design.

**Table 1.** Test resistance  $F$  calculation table.

U(m/s)	b(m)	H(m)	L(m)	i	F(N)
0.217	0.128	0.07	0.0143	0.0022	0.6182
0.244	0.128	0.092	0.0188	0.0022	0.8124
0.271	0.128	0.132	0.027	0.0022	1.1657
0.298	0.128	0.175	0.0358	0.0022	1.5454
0.325	0.128	0.18	0.0369	0.0022	1.5896
0.352	0.128	0.21	0.043	0.0022	1.8545
0.375	0.128	0.22	0.0451	0.0022	1.9428

Another common parameter for calculating the resistance of the ecological channel is the roughness, and the calculation of the roughness needs to be based on the relationship between the  $C_D$  of the plant drag coefficient and the resistance  $F$ . The relationship between water flow shear force and  $C_D$  in ecological channels is:

$$F_{Di} = \frac{1}{2} C_D \rho A_{pi} u^2 \quad (3)$$

where  $F_{Di}$  = the drag force of the water flow on the plant,  $C_D$  = the drag coefficient of the plant;  $A_{pi}$  = the plant in the unit area.  $A_{pi}$  = the water retaining area of the plant per unit area. Based on the parameters of vegetation density, size, and section average flow velocity in the canal, according to formula (1) obtain  $C_D$ . The relationship between the roughness  $n$  and the plant drag coefficient  $C_D$  can be calculated by the following S.Petryk.GBosmajianIII formula:

$$n = R^{2/3} \sqrt{\frac{C_D e'}{2g}} \quad (4)$$

The  $R$  = the hydraulic radius and is calculated as  $R = V/NA$ , m,  $C_D$  = the drag coefficient previously requested.  $e' = NA/A$ , where  $N$  is the number of cylinders in bed area  $A$  (here  $A = 1 \text{ m}^2$ ) and  $A'$  is the projected area of the upstream face in the direction perpendicular to the vegetation and water flow, where  $A' = \text{diameter of vegetation } d \times \text{water depth } h$ . For the FengHui trunk canal ecological rehabilitation, the vegetation density ( $54 \text{ plants/m}^2$ ) are used for resistance calculation, and the length of the channel ecological belt is 2 m at the experimental condition of the water depth of 0.26 m. The results are shown in table 2.

**Table 2.** Drag coefficient  $C_D$  and comprehensive roughness  $n$  calculation table.

U (m/s)	Drag coefficient $C_D$	Roughness $n$
0.217	1.0174	0.0612
0.244	1.0603	0.0624
0.271	1.2233	0.0671
0.298	1.3636	0.0708
0.325	1.3358	0.0701
0.352	1.4124	0.0721
0.375	1.3444	0.0703
0.406	1.1754	0.0657

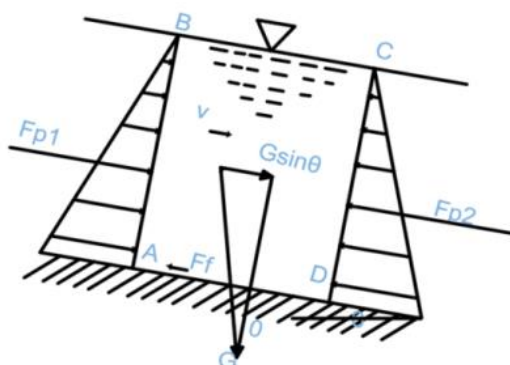
#### 4. Channel energy loss under different ecological section design

$$C = \frac{1}{n} R^{\frac{1}{6}} \quad (5)$$

$$Q = AV = AC\sqrt{Ri} = \frac{i^{\frac{1}{2}} A^{\frac{5}{3}}}{n X^{\frac{2}{3}}} \quad (6)$$

where  $Q$  = the design flow of the trunk canal,  $A$  = the cross-sectional area,  $V$  = the water velocity;  $C$  = the Manning coefficient;  $i$  = the channel slope. Based on the results of resistance calculation, the parameters of each section of scheme 1 are brought into the Manning formula, and the water depth of scheme 1 is calculated by the interpolation method and the approximate value is 0.695 m. In Schemes 2 and 3, the design water depth  $h$  is 0.864 m and 0.653 m. In the uniform flow of an open canal, the

flow velocity is constant, and as shown in figure 6, the energy loss of the water flow in the canal is the reduced gravity potential energy along the flow.



**Figure 6.** The analysis of the force of the flow in the canal.

$$F_{p1} + G \sin \theta - F_{p2} - F_f = 0 \quad (7)$$

Because  $F_{p1} = F_{p2}$ ,  $G \sin \theta = F_f$ , the energy loss is  $E = mgh$ ,  $h$  = the reduction in the absolute height of the water body per unit of time. For a unit volume of water, the greater the drop height, the greater the energy loss. Therefore, it can be concluded from the terms of energy loss,  $E_3 < E_1 < E_2$ .

In order to reduce the amount of work, the tentative calculation of the slope change of the slope protection under the condition that the projection plane of the bottom surface of the canal and the slope is unchanged (table 3). The ecological vegetation area and the smooth concrete area at the bottom of the canal remain unchanged. Therefore, the ecological change of the canal will not be large, and the comprehensive roughness  $n$  at the bottom of the canal will not change. A change in slope will lead to a change in the depth of water, which in turn affect the flow rate  $v$  resulting in different energy losses.

**Table 3.** Flow velocity calculation table under different slopes.

m	1.5	1.3	1.4	1.6	1.7
Scheme 1 h (m)	0.695	0.708	0.701	0.689	0.683
Scheme 1 v (m/s)	2.408	2.409	2.41	2.407	2.407
Scheme 2 h (m)	0.864	0.883	0.873	0.855	0.847
Scheme 2 v (m/s)	1.931	1.868	1.866	1.856	1.863
Scheme 3 h (m)	0.653	0.664	0.658	0.647	0.642
Scheme 3 v (m/s)	2.586	2.591	2.587	2.59	2.588

From the table, we can see that after changing  $m$ , the  $h$  of water will change, but the change speed of  $V$  will be very small. According to the previous formula, the fluctuation of energy loss will be smaller. But the cost of the slope change is very expensive, and the amount of construction of the slope is very large and the time limit will be prolonged. Therefore, the original design size does not change the  $m$ .

Different design methods and materials used for irrigation ecological canals will lead to different construction cost. Under the same effect, we should choose the method of shorter duration and lower cost. For comprehensive calculation, from the perspective of price analysis per square meter of

remodeling, the second laying price of the program is relatively expensive, the costs of the first and the third scheme are similar. From the perspective of energy loss, the second scheme is better than the first scheme and the first scheme is better than the third scheme. Therefore, we adopt the second scheme (cross laying) after considering energy loss and economic factors.

## 5. Conclusion

This paper proposed the ecological rehabilitation of the main canal, the ecological function of the channel can be restored on the premise of ensuring the canal water transport capacity.

- To ensure the ecology of the drainage canal, the horizontally laid, fully laid and cross laid methods shall be adopted to arrange the bottom vegetation. Flow over vegetation patch was analyzed in experimental channel to determinate flow resistance in ecological channel. Based on momentum balance principle and improved hydraulic radius model, the determination of drag force and mean roughness are proposed effectively.
- According to the basic parameters in canal, the design water depth of the three schemes is deduced by using the interpolation method, and finally the scheme of cross laying of ecological vegetation is selected from the perspective of energy and economy. According to the principle that the velocity along the path is constant in the open canal uniform flow, the energy loss of the flow in the canal is the gravitational potential energy reduced by the flow along the path, obtained three schemes of energy loss  $E_3 < E_1 < E_2$ .
- By calculating the channel flow velocity  $V$  under different slope coefficients  $m$ , our study finds that the flow velocity  $V$  does not change much, so that the energy loss does not change much. Under the principle of minimum engineering quantity, the design does not change the initial slope coefficient  $m$ . After investigating the price of local materials, choose the plan of cross-laying ecological vegetation from the perspective of price preference and energy loss.

## Acknowledgments

The authors express gratitude for the financial support from the National Natural Science Foundation of China (Grant No. 51509248), National Key R & D Program of China (Grant Nos. 2017YFC0403203, 2016YFC0400207, 2017YFD0701000 and 2016YFD0200700), Jilin Province Key R&D Plan Project (20180201036SF), Jilin Province Education Department "13th Five-Year" Science and Technology Project (JJKH20170519KJ), Jilin Province Science and Technology Office of key scientific and technological projects (20170204008SF).

## References

- [1] Li J, Wu Q H, Hou S C and Zheng M L 2013 Application and research of water restoration technology in the design of ecological channels *Technol. Innov. Appl.* **4** 25-6
- [2] Huang Z H, Chen L, Qiu X X, Jiang Y G and Yang L 2011 Landscape design pattern of cross-town canal ecological landscape in large-scale irrigation area of yellow river diversion *Water Resour. Plan. Design* **4** 85-7
- [3] Gu H, Huang W Y, Li J G, Luo Y F and Sun Y 2012 Ecological Lining types of canals in Gaoyou irrigation district and their comprehensive evaluation *Water Saving Irrig.* **12** 51-3
- [4] Cui S F, Sun Z Y, Shu T Q, Liu W P and Zhang S 2015 Preliminary research on the construction of Handun Ecological Irrigation District China *Water Resour.* **15** 53-4
- [5] Peng S Z, Ji R X, Yang S H and Liu X Y 2014 Construction and prospect of water-saving ecological irrigation district *Adv. Sci. Technol. Water Resour.* **34** 1-7
- [6] Chen D Q 2016 Existing problems in the construction of ecological irrigation districts and their countermeasures *Scientific and Technological Innovation* **24** 122
- [7] Gu B J 2006 Research on the construction technology of ecological ditch form in irrigation district China *Rural Water Hydropower* **10** 4-6
- [8] Wang P F, Chao W and Zhu D Z 2010 Hydraulic resistance of submerged vegetation related to effective height *J. Hydrodyn.* **22** 265-73



- [9] Wilson C and Horritt M S 2010 Measuring the flow resistance of submerged grass *Hydrol. Process* **16** 2589-98
- [10] Tang H W, Yan J, Xiao Y and Lü S Q 2007 Study on Manning's drag coefficient in rivers with plants *J. Hydraul. Eng.* **38** 1347-53
- [11] Green J C 2006 Effect of macrophyte spatial variability on channel resistance *Adv. Water Resour.* **29** 426-38
- [12] O Hare M T, Mogahey C, Bissett N, Cailes C, Henville P and Scarlett P 2010 Variability in roughness measurements for vegetated rivers near base flow, in England and Scotland *J. Hydrol.* **385** 361-70