12th International Conference on Hydroscience & Engineering
Hydro-Science & Engineering for Environmental Resilience
November 6-10, 2016, Tainan, Taiwan.

Analysis of stage-discharge relationship with neural network in varying backwater zone of Three Gorges Project

Zhongchao Yang, Xin Liu
Key Laboratory Inland Waterway Regulation Engineering of Ministry of Communication Chongqing Jiaotong University
Chongqing, China

ABSTRACT

The stage-discharge relationship is the basic data of hydropower, flood control, shipping and other engineering's design. After the normal operation of Three Gorges Reservoirs, the channel between the Changshou of the Yangtze River and Jiangjin became the varying backwater zone. And stage-discharge relationship is not a single correspondence anymore, but a complicated loop curve which is a highly nonlinear relationship. It is quite difficult to fit relation curve with the traditional method ,Using these observed data of water level, discharge in Cuntan hydrological station and water level of Three Gorges dam, the paper has established stage-discharge relationship with the improved BP neural network which has the powerful ability to deal with the nonlinear system. Simulation results show that compared to the curve fitting method, the neural network algorithm can achieve higher fitting precision, which is an efficient and simple method to obtain stage-discharge relationship of Three Gorges Reservoir varying backwater zone.

KEY WORDS: Three Gorges Reservoirs;stage-discharge relationship; loop curve; neural network; varying backwater zone

INTRODUCTION

The stage-discharge relationship is used to describe the relationship between the water level and the flow of Hydrologic station, which is the basic data of the engineering design of hydropower, flood control, shipping and so on. From the beginning of October 2010, Three Gorges Reservoir is operating by 175-145-155m water level scheduling. On influence of damming, the end of backwater reach at Huanghuaqi near Jiangjin when water level of the dam is 175m in Non flood season, and at Changshou when water level of the dam is 145m in flood season. The reach of Changshou to Jiangjin became varying backwater area, and has dual characteristics of reservoir and natural channel. The river original hydraulic characteristics has changed,Correspondingly the stage-discharge relationship is not a simple curve originally but a complex loop curve, so it is difficult to determine the stage-discharge relationship correctly. For this problem, Many scholars[1-6] were studied extensively from many aspects of stage-discharge relationship origin, curve fitting, data compilation. The traditional curve fitting is one of method described stage-discharge relationship, but the method is rather complex [3-5].So the paper established stage-discharge relationship with the improved BP neural network which has the powerful ability to deal with the nonlinear system based on main parameters of the measured discharge, water level of Cuntan hydrological station and the water level of Three Gorges dam.

THREE GORGES RESERVOIR OPERATING SCHEDULING

According to preliminary design, Three Gorges reservoir operates normally by scheduling as shown in Figure 1. During June to September in flood season, Three Gorges reservoir water level of the dam fluctuats around 145m which is limited water level of flood control. Early in October, Three Gorges reservoir starts water storage and water lever of the dam rose to normal work water lever 175m, among January to May called by Pre-flood Falling Stage, the water level of the dam falls from 175m to 145m.Compared the original design water level process with the actual water level of the dam among 2011-2012, the actual reservoir operation is different from design scheduling.

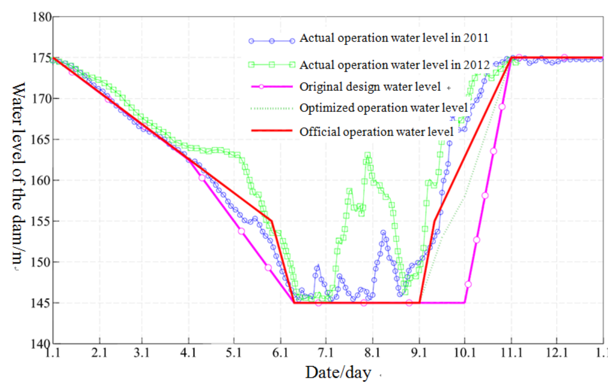

Fig. 1 Three Gorges reservoir water level of the dam operation curve

According to 《Three Gorges reservoir optimization scheduling scheme》and official operation schedule approved by the state Flood Control and Drought Relief Headquater, besides think of the actual scheduling curve among 2011 to 2012, the final operation schedule is used that official operation schedule approved by the state Flood Control and Drought Relief Headquater as shown in Table 1.

Table 1 Official operation schedule of Three Gorges reservoir

Date	**1.1**	**5.25**	**6.10**	**8.31**	**9.10**	**10.31**
Water level/m	**175**	**155**	**145**	**145**	**155**	**175**

THE STAGE-DISCHARGE RELATIONSHIP OF CUNTAN HYDROLOGICAL STATION BEFORE DAM

The backwater does not impact on the stage-discharge relationship of Cuntan hydrological station before Three Gorges Reservoir become dam. The stage-discharge relationship of Cuntan hydrological station before dam is fitted as follow equations based on measured water level Z_{T0} and discharge Q_T data during 1955~2007.

Q_T<10000m^3/s：

$$Z_{T0} = -2.124526\times10^{-23}Q_T^6 + 8.578838\times10^{-19}Q_T^5 - 1.420914\times10^{-14}Q_T^4 + 1.252869\times10^{-10}Q_T^3 - 6.571865\times10^{-7}Q_T^2 + 2.822356\times10^{-3}Q_T + 154.0348 \quad (1)$$

Q_T=10000~60000m^3/s：

$$Z_{T0} = -9.267402\times10^{-28}Q_T^6 + 2.359726\times10^{-22}Q_T^5 - 2.402405\times10^{-17}Q_T^4 + 1.275049\times10^{-12}Q_T^3 - 3.939026\times10^{-8}Q_T^2 + 1.089361\times10^{-3}Q_T + 156.2701 \quad (2)$$

Q_T>60000m^3/s：

$$Z_{T0} = -7.430017\times10^{-28}Q_T^6 + 2.5757304\times10^{-22}Q_T^5 - 2.402405\times10^{-17}Q_T^4 + 2.660312\times10^{-12}Q_T^3 - 1.072536\times10^{-7}Q_T^2 + 2.604131\times10^{-3}Q_T + 144.0603 \quad (3)$$

THE CRITICAL WATER LEVEL INFLUENCED BY BACKWATER

The influence of water level of Three Gorges dam on the stage-discharge relationship of Cuntan hydrological station is described by figure 3 which is plotted based on the measured average daily water level of the Cuntan hydrological station, the water level of the dam and backwater height ΔZ_{T30} that is defined as follows:

$$\Delta Z_{T30} = Z_{T3} - Z_{T0} \quad (4)$$

Where Z_{T3} is water level of the Cuntan hydrological station after dam Z_{T0} is water level of Cuntan hydrological station for the same flow before dam

It is seen clearly in Figure 2 that backwater height is 0m when the water level of the dam is less than 156m, which means no effect of the water level of the dam on the stage-discharge relationship of cuntan hydrological station.

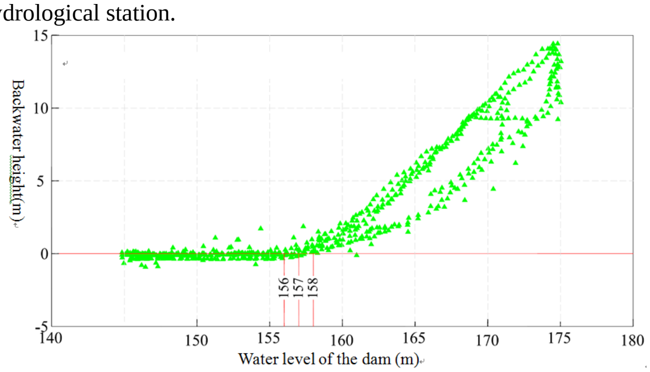

Fig. 2 the influence of water level of the dam on the stage-discharge relationship of Cuntan hydrological station

THE STAGE-DISCHARGE RELATIONSHIP OF CUNTAN HYDROLOGICAL STATION AFTER DAM

According to the previous analysis, when Z_3<156m, the stage-discharge relationship is Calculated by formula(1)~(3), May to September every year belong to this case. However, when Z_3>156m, the stage-discharge relationship is loop curve so that it is difficult to directly express, Curve fitting formula in accordance with the flow segment is used as follows:

Q_T≤5000m^3/s and ΔZ_{30}≥-4m：

$$\Delta Z_{T30} = -1.152981\times10^{-6}\Delta Z_{30}^6 + 4.483736\times10^{-5}\Delta Z_{30}^5 - 5.473517\times10^{-4}\Delta Z_{30}^4 + 4.430784\times10^{-4}\Delta Z_{30}^3 + 4.431298\times10^{-2}\Delta Z_{30}^2 + 5.889135\times10^{-1}\Delta Z_{30} + 1.561540 \quad (5)$$

Q_T=10000~15000m^3/s and ΔZ_{30}=-10~12m：

$$\Delta Z_{T30} = -4.092863\times10^{-7}\Delta Z_{30}^6 - 7.318551\times10^{-6}\Delta Z_{30}^5 + 5.819553\times10^{-5}\Delta Z_{30}^4 + 4.820069\times10^{-4}\Delta Z_{30}^3 + 2.332896\times10^{-2}\Delta Z_{30}^2 + 5.727552\times10^{-1}\Delta Z_{30} + 3.048509 \quad (6)$$

Q_T=15000~20000m^3/s and ΔZ_{30}=-10~9m：

$$\Delta Z_{T30} = 3.438628\times10^{-6}\Delta Z_{30}^6 + 2.858969\times10^{-5}\Delta Z_{30}^5 - 5.995501\times10^{-4}\Delta Z_{30}^4 - 4.510486\times10^{-3}\Delta Z_{30}^3 + 4.295703\times10^{-2}\Delta Z_{30}^2 + 7.139154\times10^{-1}\Delta Z_{30} + 4.096424 \quad (7)$$

Q_T>20000m^3/s and ΔZ_{30}<0m：

$$\Delta Z_{T30} = 6.285216\times10^{-4}\Delta Z_{30}^3 + 3.533197\times10^{-2}\Delta Z_{30}^2 - 3.555317\times10^{-1}\Delta Z_{30} + 4.751563 \quad (8)$$

Q_T=5000~10000m^3/s

linear interpolation calculated by equations (5) and (6)

Where $\Delta Z_{30} = Z_3 - Z_{T0}$, $\Delta Z_{T3} = Z_{T3} - Z_3$

Z_3 is the water level of the dam

STAGE-DISCHAGE RELATEIONSHIP BASED ON ARTIFICIAL NEURAL NETWORK

BP neural network[7] is a non-parametric prediction method, relying solely on sample data driven to seek the mapping relationship between data. At the same time, for essentially nonlinear problem it has these abilities of self-learning, self-adaption and fault-tolerant, so BP neural network is a general scientific predicting models and to solve the highly complex nonlinear problem.

BP neural network of Stage-discharge relationship was established by using Matlab neural network toolbox. As shows in figure 3, this predicting model comprises input, two hidden layers and output. Input consists of two neural units where input discharge and water level of the dam respectively. According to the Kolmogorve theorem, the first hidden layer has 6 neural units, transfer function employs "logsig", the second hidden layer has two neural units, transfer function uses "purelin". The output includes one nerve units, which is measured water level or predicted water level.

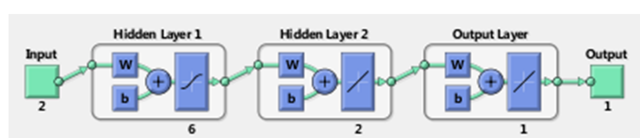

Fig. 3 BP neural network structure

Using the measured discharge ,water level of Cuntan hydrological station, water level of the dam in 1995~2012 as sample data, the neural network is trained fully. From the previous analysis, we can know that when the water level of the dam is lower than 156m, the backwater of Three Gorges has no influence on the stage ~ discharge relationship of Cuntan hydrological station. Therefore, the water level of the dam adopt 156m among 1995-2007 when Three Gorges Reservoir has not been built.

MATLAB neural network toolbox is divided sample data automatically into three parts: Training set, Validation set and Test set, these three data sets do not overlap each other. Training set is used to train neural networks, Validation set is used to detect whether or not to achieve convergence, Test set is used to test the training effect. The every correlation coefficient R of Train, Validation, Test and All is more than 0.9988 as shown in figure 4, it shows that the neural network simulation effect is well.

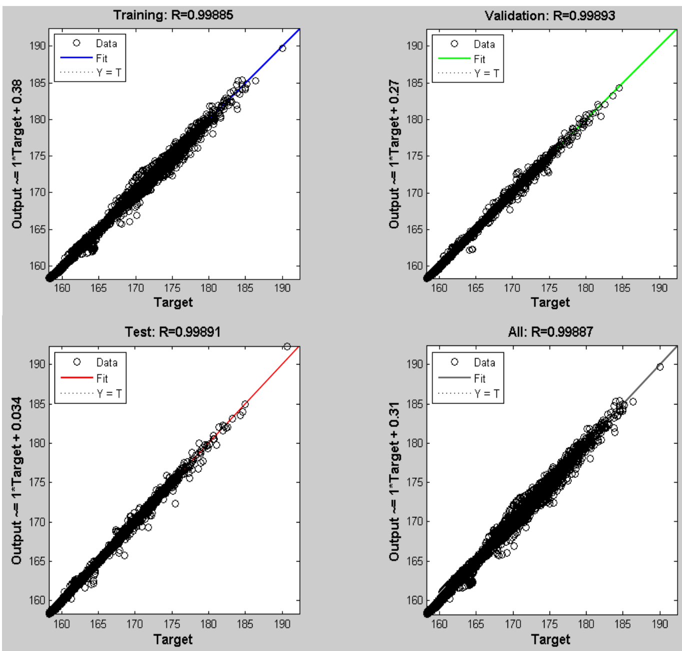

Fig. 4 The correlation coefficient R of Train, Validation, Test and All

Figure 5 demonstrates calculated results by the neural network. Comparison with measured results, the simulation results before dam is better than after dam, because the measured dada before dam include 52 years (within 1995 to 2007) so as to have more training sample data, however training sample data after dam has only 4 years measured dada(within 2008 to 2012). Along with increasing the measured sample after dam to further train neural network, the simulation precision is being improved constantly.

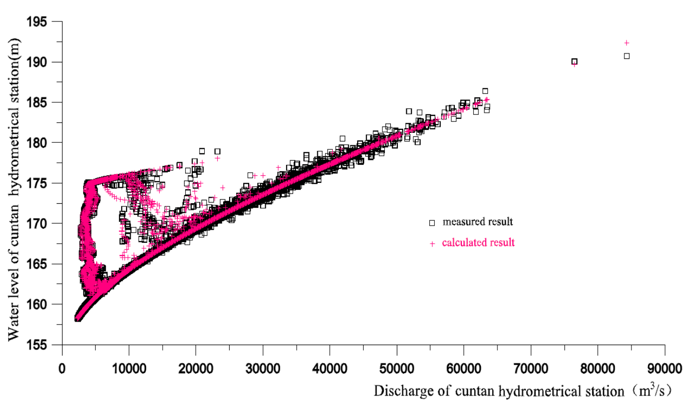

Fig. 5 Stage-discharge relationship of Cuntan hydrological station

COMPARATIVE ANALYSIS

Comparison of calculated results by neural network and by curve fitting formula in table 2, it is show that these calculated results all are basically consistent with measured results, so neural network method is effective to establish the stage-discharge relationship in varying backwater zone of Three Gorges Project.

Table 2 Comparison of calculated results by neural network and by curve fitting formula

Case	Q_T(m³/s)	Z_3(m)	Z_{T3}(m)	Z^1_{T3}(m)	Z^2_{T3}(m)	$Z^1_{T3}-Z_{T3}$	$Z^2_{T3}-Z_{T3}$
1	4300	173.082	173.213	173.555	173.574	0.342	0.361
2	11100	159.110	165.437	165.767	165.224	0.330	-0.213
3	28000	145.000	172.840	172.867	172.952	0.027	0.112
4	62400	145.000	184.922	184.972	185.146	0.050	0.224

Z^1_{T3} is calculated results by the neural network; Z^2_{T3} is calculated results by curve fitting formula.

CONCLUSIONS

The stage-discharge relationship is the basic data of hydropower, flood control, shipping and other engineering's design. After the normal operation of Three Gorges Reservoirs, the channel between the Changshou of the Yangtze River and Jiangjin became the varying backwater zone. And stage-discharge relationship is not a single correspondence anymore, but a complicated loop curve which is a highly nonlinear relationship. It is quite difficult to fit relation curve with the traditional method, Using these observed data of water level, discharge in Cuntan hydrometrical station and water level of Three Gorges dam, the paper has established stage-discharge relationship with the improved BP neural network which has the powerful ability to deal with the nonlinear system. Simulation results show that compared to the curve fitting method, the neural network methods can achieve higher fitting precision, so that the neural network is an efficient and simple method to establish stage-discharge relationship of Three Gorges Reservoir varying backwater zone.

REFERENCES

Richang, T. (1994). Impact of river bend cut-off of lower Jingjiangriver on the river and Dongting lake. Yangtze River, 4, 24-26.

Xiaohu, G., Geng, Q., Yonghui, Z.(2011). Changes of the Stage-Discharge Relation in Jingjiang River after the Impoundment of Three Gorges Reservoir Journal of Yangtze River Scientific Research Institute, 7, 82-85.

Binyi, G., Zhengzui, L. (1998). The Direct Method for Fitting a Loop Curve of Stage-Discharge Relationship during Flood Season Hydrology. 5, 26-29.

Yanfei, W., Yanrong, H. (2011). Application of Subsection Power Function in Fitting of Stage-discharge Relation Curve Based on Convexity and Monotonicity Preserving. HongShui River, 6, 19-22.

Zuotao, X., Xiaofeng, Z., Guangming, T., Fangli, Y.(2005). Forecasting of stage-discharge relationship of Luoshan on the Yangtze River. Engineering Journal of Wuhan University, 2, 15-19.

Shuhan, Z., Tianyuan, X., Hougui, L. (2012). Analysis of compilation optimization of hydrological data in upstream and downstream stations of Three Gorges Project before and after impoundment. Yangtze River, 23, 18-21.

Pin, Z.(2013). MATLAB-design and application of neural network[M]. Tsinghua University Publishing.