APPLICATION OF A ROUGHNESS IDENTIFICATION MODEL TO ASSESS THE VARIATION OF ROUGHNESS COEFFICIENT OF THE DUONG RIVER IN FLOOD SEASON

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Abstract: *For alluvial rivers, the variation of the roughness coefficient could be attributed to the variation in bedforms and the higher energy and momentum losses for picking up and transporting the sediment of high flows. The effects of these factors on the roughness coefficient are usually needed to measure directly velocity/flow or conduct experiments. These methods are expensive and time consuming. In this study, a roughness identification model was applied to investigate of the variation of the roughness coefficient with time in the Duong River for different flood events in different years. The results show the consistent and general trend of the variation of roughness coefficient of the river in the flood season. The study indicated that this method can be used as a means to assess the variation of the roughness coefficient with time for rivers.*

Keywords: roughness coefficient, variation of roughness coefficient, roughness identification model, flood event, flood season.

1. INTRODUCTION

An accurate estimation of roughness coefficients is of vital importance in any open channel flow study. The estimation of this coefficient is not a trivial task as it depends on many factors such as surface roughness, vegetation condition, cross-sectional shape and channel irregularity. For a natural channel, the changes in vegetation or water temperature could result to the variation of the roughness coefficient (Chow, 1959; U.S. Army Corps of Engineers, 1993; Panigrahi and Khatua, 2015). Therefore, it is necessary to investigate the variation of this coefficient to improve the accuracy of hydraulic computation.

There are some previous studies related to the temporal variation of roughness coefficient (Manning's n). Shih and Rahi (1982) studied on seasonal variation of n in a slough marsh of 0.65 km wide and 6.77 km long with hearily vegetation. The study conducted flow velocity measurement in 4 sites with a number of subsites once a month during August through November in 1978 and June and July in 1979 using water current meter and dye technique. Then the roughness coefficient was calculated using Chezy-Manning equation. The results showed that n was function of depth, growing season, vegetation growth control and vegetation density. n values in the marsh was significantly increased by vegetation, the relationship between n values and wet growing season was expressed well by an exponetial function. Teixeira et al. (2018) used observed data of 7 gauge station of Doce River in Brazil to calculate and assess the variation of roughness coefficient using Chezy-Manning equation where the friction slope was adopted as river bed slope. Valentine et al. (2001) conduct an experiment study for alluvial beds. The results showed that the variation in bedforms of alluvial bed rivers is the most dominant factor affecting on the variation. Beside the changes in bedforms, the variations may also be attributed to the higher energy and momentum losses for picking up and transporting the sediment of high flows. Bao et al. (2009) used observed data to analyse the roughness variation and proposed a new method of roughness dynamic correction combined with

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the stage model. The model was applied to the tidal reach of the Caoe River. The study showed that the roughness dynamic correction can improve the simulation accuracy of the stage model, and reduce the errors at peak stages.

Previous studies (Shih and Rahi, 1982; Teixeira et al. (2018); Valentine et al. (2001); Bao et al. 2009) analysed the change in roughness coefficient with time mainly using flow and velocity measurements or experiments. These methods are very expensive and time consuming. Moreover, in their studies, value of n was calculated from the Manning-Chezy equation where the friction slope was adopted as of river bed slope that is not accurate especially in flood season or tidal regions (Teixeira et al. 2018; Bao et al. 2009) These limitations maybe overcome by using inverse problem to identify the value of roughness coefficient.

In this study, a roughness identification model was developed and applied to the Duong River in the Red River system of Vietnam as a case study to investigate the variation of roughness coefficient with time in flood seasons. The results show that by identifying roughness coefficient from different flow events at different times during the flood season for several years could provide a general picture of the variation of the roughness coefficient with time during the flood season for this river.

2. METHODOLOGY

The unsteady one-dimensional open-channel equations can be derived from the principles of conservation of mass and momentum resulting in equations known as the Saint-Venant equations:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q \qquad (1)$$

$$\frac{\partial Q}{\partial t}+2\beta\frac{Q}{A}\frac{\partial Q}{\partial x}+\left(gA-\beta\frac{Q^2B}{A^2}\right)\frac{\partial Z}{\partial x}-\beta\frac{Q^2B}{A^2}S_0+gAS_f=0 \qquad (2)$$

where A is the wetted cross-sectional area; Q is the discharge; Z is the water stage or surface water elevation; q is the lateral inflow per unit length of channel; B is the channel width at the surface water; β is the momentum correction factor; g is the gravity acceleration; Y_O is the channel bed slope; S_f is the friction slope; x and t are space and time variables, respectively.

The friction slope S_f is given by Manning's equation. For compound channels, the channel cross-sections are divided into main channel and floodplains. The assumption is that friction slope is constant in main channel and floodplains. The conveyance is computed using divided section method in which for any depth the conveyance of the compound section is the sum of the main channel and floodplain conveyances. Then:

$$S_f=\frac{Q_c|Q_c|}{K_c^2}=\frac{Q_f|Q_f|}{K_f^2}=\frac{Q|Q|}{(\sum K_i)^2} \qquad (3)$$

where: Q_c, Q_f and Q are respectively, the discharge of main channel, floodplains, and the total discharge of the section, K_c and K_f are the conveyances of main channel and floodplains and which are determined as follows:

$$K_i=\frac{A_iR_i^{2/3}}{n_i} \qquad (4)$$

where: Ki, Ai, Ri and ni are conveyance, wetted area, hydraulic radius and Manning's roughness coefficient of i sub-cross-section respectively.

In this study, the Saint-Venant equations are solved by the implicit finite difference Preissmann box scheme. The algebraic equation system is linearised and solved by using double sweep algorithm (Liggett and Cunge, 1975; Cunge et al. 1980).

In hydraulic modelling, the procedure of unsteady flow computations usually includes three steps: (i) calibration, (ii) verification/validation and (iii) computation of different scenarios for different purposes. The calibration step is to determine the values of roughness coefficient(s). The traditional method uses trial and error method. This method suffers from subjectivity and by being inefficient and time-consuming. To overcome these disadvantages, automatic optimisation methods may be applied. This approach is also known as the roughness identification problem or inverse problem which will be focused on in this study.

The roughness identification model was developed by combining the hydraulic sub-model (to solve the Saint Vernant equations) and the optimisation sub-model (to identify the value of roughness coefficient) (Nguyen, 2006). The capability for the identification of the roughness coefficient is based on minimizing a chosen objective function. The selection of objective functions is one of the factors affecting the quality of identification problem. Nguyen and Fenton (2004) and Khabiti et al. (1997) investigated different types of objective function and showed that least square objective function had the best performance. Therefore, in this study the objective function sum of square of absolute errors between observed and simulated stages/discharges is considered as follows:

$$\min \sum_{j=1}^{N} \sum_{i=1}^{M} (Y_{Oi,j} - Y_{Si,j})^2 \qquad (5)$$

where the subscripts i, j correspond respectively to value at different times and locations, M is number of observation times, N is number of observation stations, Y_O is observed discharge or stage, Y_s is simulated discharge or stage.

Based on the chosen least square objective function, a direct search optimisation algorithm proposed by Powell (1965) and improved by Acton (1970) is adopted for the optimisation sub-model. This method is an extension of the basic pattern search method. It is the most widely used direct search method of conjugate directions (Rao, 1996). It is an efficient method for finding the minimum of a function of several variables without calculating derivatives. A conjugate directions method will minimise a quadratic function in a finite number of steps. Since a general non-linear function can be approximated reasonably well by a quadratic function near its minimum, a conjugate directions method is expected to speed up the convergence of even general nonlinear objective functions. Also, the upper and lower constraints are introduced in the model to restrict the coefficients to physically realistic values. The roughness identification procedure is illustrated in Figure 1. The computer code for the model was written in FORTRAN 90.

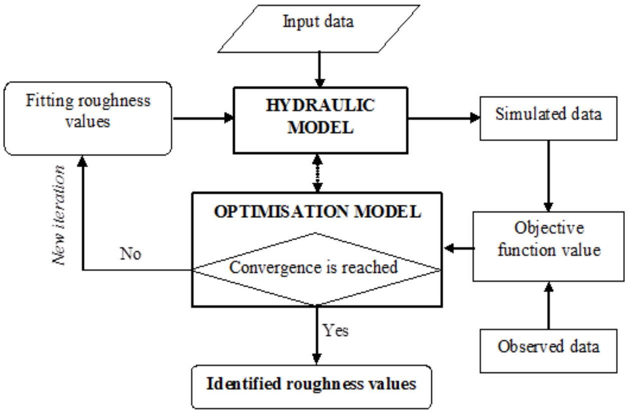

Figure 1. The roughness identification procedure

One of the advantage of the roughness identification model as mentioned about is that the values of identified roughness coefficient are not affected by subjectivity. Therefore, it can be applied to investigate the variation of roughness coefficient with time by identifying its values corresponding different flood events with different time during flood seasons.

3. CASE STUDY

3.1. Duong River

The model for identification of roughness coefficients was applied to the Duong River in Red River delta, Viet Nam to assess the variation of roughness coefficient with time in the flood season. The river is one of the main distributaries of Red River that conveys the water from Red River to Thai Binh River. This river is an alluvial river. Therefore, during flood season with large flows the high velocities the bedforms are changed significantly resulting in the variation of roughness coefficient. The computed reach is 61.71 km long from Thuong Cat to Pha Lai.

There are several stations along the Duong river, e.g. Thuong Cat and Ben Ho, and Pha Lai (about 0.6 km from the confluence of the Thai Bình and Duong rivers) (see figure 2). The discharge hydrograph at Thuong Cat was chosen as the upstream boundary condition and the stage hydrograph at Pha Lai was adopted as the downstream boundary condition. The stage observation data at Ben Ho was used for identification of roughness values of main channel and floodplains by minimizing the differences between computed and measure stages at this station. The flood season is from June to October and usually the main floods occurs from middle of July to end of August.

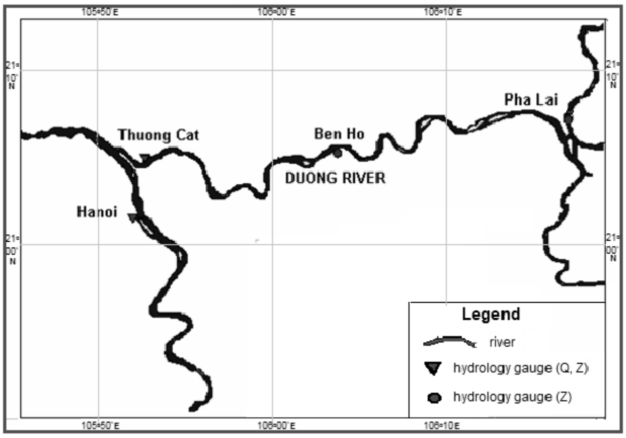

Figure 2. Duong River and the gauging stations along the river

Cross section data were obtained from the Institute for Water Resources Planning (Viet Nam) which were surveyed in the dry season in 1996. There were 33 cross sections measured along the river. The slope of the river is very flat with the average slope is 0.0001 or 10cm/km. The main channel of the river is an alluvial channel. Because the roughness conditions are similar along the computed reach and there is one gauging station at Ben Ho that can be used to identified the roughness therefore, in this study, the roughness coefficients of the main channel are considered as constants for the whole reach. Different flood events which occurred during the validity of the cross section survey will be considered.

3.2. Results and discussion

In this study, several flow events before, during and after the main flood events of the years from 1995 to 1998 (close with the time when the cross-section data were surveyed) have selected to identify the values of roughness coefficients.

Each selected year, three to five events are selected to identify the values of roughness coefficients. Table 1 shows some output results from the model including the identified roughness coefficients, number of iterations and root mean square errors (RMSE) between observed and computed data. The ability to identify the values of roughness coefficient of the model is proved by the shapes and magnitudes of observed and simulated hydrographs which are very close to each other. Figure 3 illustrates the observed and simulated stage hydrographs at different gauging stations by using the identified roughness coefficients from the different main flood events from 1995 - 1998 as examples.

Table 1. Identified roughness coefficients from different flood events

Year	**Flood event**	**Identified n**		**No of iterations**	**RMSE** (m)
		n_c	n_f		
1995	05/06-14/06	0.0262	0.0625	13	0.0459
	20/07-02/08	0.0322	0.0613	14	0.0378
	14/08-31/08	0.0332	0.0612	22	0.0621
	19/09-28/09	0.0328	0.0615	15	0.0351
	03/10-16/10	0.0328	0.0619	11	0.0423
1996	07/07-15/07	0.0271	0.0623	12	0.0378
	19/07-02/08	0.0304	0.0612	13	0.0342
	16/08-30/08	0.0327	0.0601	19	0.054
	19/09-02/10	0.0301	0.0618	15	0.0603

Year	Flood event	Identified n		No of iterations	RMSE (m)
		n_c	n_f		
1997	22/06-03/07	0.0302	0.0621	14	0.0441
	22/07-06/08	0.0330	0.0607	21	0.0432
	18/09-30/09	0.0289	0.0619	17	0.0549
	21/10-01/11	0.0028	0.0621	12	0.0531
1998	21/06-01/07	0.0273	0.0618	13	0.0459
	26/07-05/08	0.0337	0.0615	15	0.0639
	28/08-09/09	0.0301	0.0622	14	0.0306

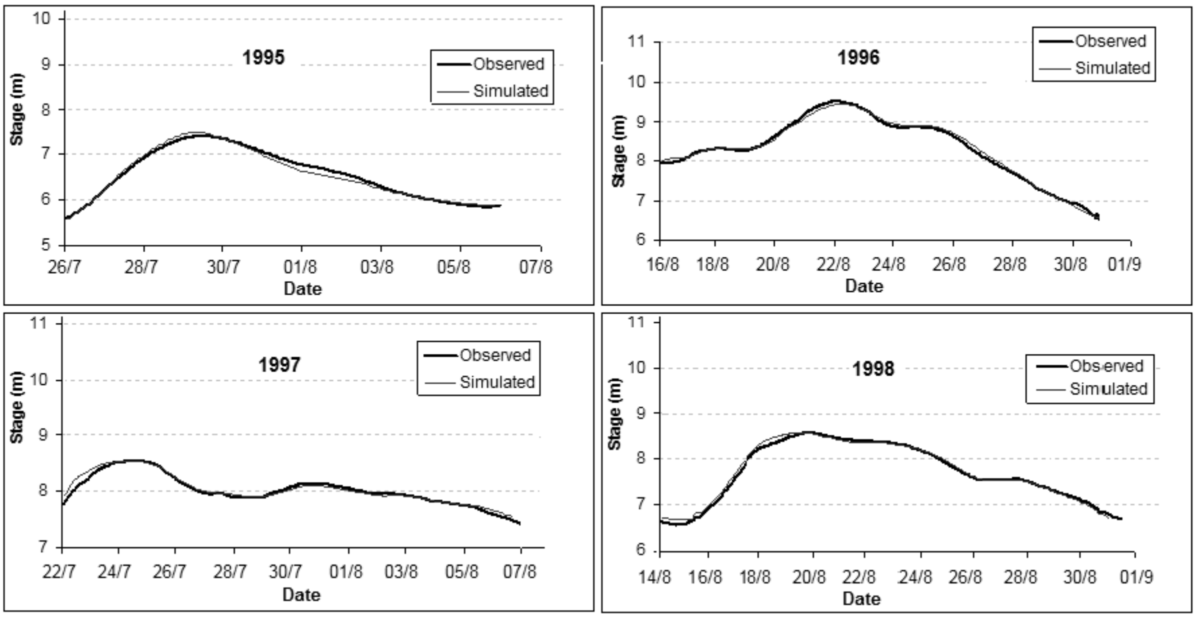

Figure 3. Observed and simulated stage hydrographs at Ben Ho for different main flood events of the years 1995 - 1998

Figure 4 illustrates the computed roughness coefficient of the Duong River at different times in the flood season. From this figure it can be seen that for every computed year, the roughness coefficient values vary with time, the values of roughness coefficient in the early flood season and the late flood season are smaller than the ones in the main flood duration (from the end of July to the end of August). The trend line in the figure shows clearly that the roughness coefficient values of the channel are lower at the beginning of the flood season ($n_c \approx 0.027$). The roughness coefficient increases slightly and reaches its highest value at the time when the main flood events occur ($n_c \approx 0.0325$). After the main flood events, the roughness coefficient value slightly decreases. At the end of the flood season, its value is still a bit larger than the values at the beginning of the flood season ($n_c \approx 0.028$). The results also indicate that the values of roughness coefficient in floodplains n_f of this reach are ranged from 0.06-0.063 (see Table 1).

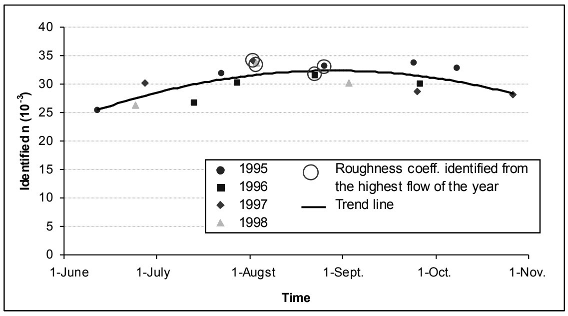

Figure 4. Variation of the roughness coefficient of the main channel with time during the flood season

The variation of the roughness coefficient of the main channel in the Duong River can be attributed to the changes of the bedforms during the flood season. These results obtained from the roughness identification model are also supported and explained by the experimental study of Valentine et al. (2001). Their study indicated that with an increase in hydraulic radius the roughness coefficient value increases. It is specified that this increase is due to an increasing bedform effect which is consistent with observed two-dimensional dunes. Beside the changes in bedforms, the higher value of roughness coefficient during the main floods may also be attributed to the higher energy and momentum losses for picking up and transporting the sediment of high flows. This variation also supported from the study on the sediment of the of Red river system (The Institute of Water Resources Research 2004) that indicated the sediment discharge and density are very different between the dry season and the flood season. For the Duong River, the sediment volume in the flood season occupies 92% of the annual sediment volume causing the bedform variations.

The investigation of the variation of the roughness coefficient in the Duong River using the roughness identification model indicates that this method can be used as a simple means to estimate the variation of the roughness coefficient during the flood season for alluvial rivers.

4. CONCLUSION

In this study, the roughness identification model was applied to investigate of the variation of the roughness coefficient with time in the Duong River for different flood events in different years. The results show the consistent and general trend of the variation of roughness coefficients of the main channel and floodplains in the flood season. At the beginning of flood season, the roughness coefficient of the mainchannel has the smaller values. It increases and reaches the highest value during the main flood events. After the main flood events, the roughness coefficient decreases slowly. The results from this study indicated that this method can be used as a means to assess the variation of the roughness coefficient for alluvial rivers during flood season.

In this study, to consider the variation of roughness coefficients in flood season several flood events were selected and the identified roughness coefficients were considered as lump roughness values of main channel and floodplain of the whole reach for each flood event. This is the limitation of the study. For further study, these parameters should be considered as a function of time and space.

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Tóm tắt:

ỨNG DỤNG MÔ HÌNH XÁC ĐỊNH HỆ SỐ NHÁM ĐỂ ĐÁNH GIÁ SỰ THAY ĐỔI HỆ SỐ NHÁM CỦA SÔNG ĐUỐNG TRONG MÙA LŨ

Đối với các sông bồi tích, sự thay đổi của hệ số độ nhám được cho là do sự biến đổi của lòng dẫn và tổn thất năng lượng và động lượng trong quá trình vận chuyển bùn cát của dòng chảy, đặc biệt là trong mùa lũ. Ảnh hưởng của các yếu tố này thường đòi hỏi phải đo ddaccj vận tốc và dòng chảy hoặc thí nghiệm. Các phương pháp này tốn kém về chi phí và thời gian. Trong nghiên cứu này, mô hình xác định độ nhám đã được áp dụng để khảo sát sự thay đổi của hệ số nhám theo thời gian trên sông Đuống với các trận lũ khác nhau trong các năm khác nhau. Kết quả tính toán cho thấy một xu thế chung về sự thay đổi của hệ số nhám trong mùa lũ của sông Đuống. Kết quả nghiên cứu cho thấy có thể áp dụng phương pháp này để đánh giá sự thay đổi của hệ số nhám đối với các con sông.

Từ khóa: hệ số nhám, sự thay đổi hệ số nhám, mô hình xác định hệ số nhám, trận lũ, mùa lũ.

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