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IDENTIFICATION OF ROUGHNESS FOR FLOOD ROUTING IN COMPOUND CHANNELS

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Abstract

For flood routing problem, many rivers have compound sections and the roughness values in main channel and flood plains are considerably different. In this study, the inverse problem of estimating the roughness coefficient (Manning's *n*) has been extended for compound channels. The conveyance of compound sections is computed using a divided section method in which for any depth the conveyance is the sum of the main channel and floodplain conveyances. The values of roughness in the main channel and flood plains are identified as two different parameters using an automatic optimization method. The writers adopt the well known Preissmann's four-point different scheme to solve the Saint-Venant equations. The optimisation process involves minimising the square errors in observed values and simulated ones using the Powell algorithm. The model has been applied to the Duong River in Viet Nam where the roughness coefficient of main channel and floodplains are presented as different constant values as well as polynomial functions of stage. Several flood events are considered. The results indicate the potential applicability of the model to natural rivers.

Keywords: roughness coefficient; compound channel; main channel; flood plains; conveyance; identification.

1. INTRODUCTION

Flood routing in open channels plays an important role in river engineering and management. The basic equations can be derived from the principles of conservation of mass and momentum. The resulting equations are hyperbolic, non-linear differential equations known as the Saint-Venant equations. The channel roughness coefficients (Manning's *n*) as embedded in the momentum equation cannot be measured directly and therefore needs to be estimated. As an empirical parameter, the roughness coefficient depends on several factors including surface roughness, unsteadiness characteristics and vegetation around the section, and channel irregularity, and the exact values are often uncertain.

In unsteady open channel flow modelling, direct or explicit parameter determination using empirical methods such as Chow (1959) and Urquhart (1975) is not adequate. Therefore, the values of roughness parameters are often estimated through a trial-and-error procedure based on visual comparison of simulated and observed values. This approach suffers from subjectivity, and is tedious and time-consuming. To overcome this problem automatic optimization methods may be applied to identify the roughness values by minimizing a chosen objective function. Becker and Yeh (1972,1973) used the influence coefficient approach by minimizing the sum of squares of differences between observed data and numerically simulated values to estimate the parameters. Wiggert *et al.* (1976) employed a conjugate gradient method and formulated the objective function by using the sum of the absolute difference between observed and simulated stages and discharges at intermediate sections. Fread and Smith (1978) used a modified Newton-Raphson search technique for estimating the roughness parameter as a function of stage and discharge. They minimized the sum of the absolute value of the difference between observed and computed stages and discharges. Their method required breaking down the river into a number of single channel reaches before calibrating each reach separately. Wormleaton and Karmegam (1984) formulated the objective function in terms of relative errors using both depth and discharge values and identified the parameters with the influence coefficient algorithm and also a nonlinear least-square technique. Khatibi *et al.* (1997) used a nonlinear least square technique with three types of objective function by a modified Gauss-Newton method. They investigated the statistical behaviour of the errors induced in the identified parameter in response to Gaussian noise as normally contained in the observed data. Atanov *et al.* (1999) introduced a variational approach of Lagrangian multipliers using a least square errors criterion to estimate roughness coefficients. However, the algorithm can be applied only to simple prismatic channels. The Sequential Quadratic Programming Algorithm was used by Ramesh *et al.* (2000) to minimize the objective function based on the least square error criterion. Recently, the Limited-memory quasi-Newton method was used by Ding *et al.*(2004) to identify Manning's *n* in shallow water flows and applied to East Fork River.

In flood routing in natural rivers, many channels have compound sections and the roughness values in main channel and flood plains are usually different. However, the above studies have just considered roughness parameters in the in-bank channel. Therefore, this problem needs to extend the method to out-bank flow where flood plain roughness will obviously have to be considered. In this study the roughness identification problem has been extended for compound channels. The problem is applied to a natural river with compound channel. The performance of the model is evaluated for different flood events with different peak discharges and flooding level in flood plains.

2. METHODOLOGY

2.1 GOVERNING EQUATIONS

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:

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

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

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; S_0 is the channel bed slope; S_f is the friction slope; u_q is the x direction velocity component of the lateral inflow; x and t are space and time variables respectively.

The friction slope S_f is given by Manning's equation. For compound channels, the critical 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:

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

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: K_i, A_i, R_i and n_i 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) p. 106).

2.2 IDENTIFICATION OF ROUGHNESS PROCEDURE

The capability for the identification of the roughness coefficient of the model river is based on minimizing a chosen objective function. The procedure starts with initial estimated parameters and performs a completed simulation run. The objective functions are evaluated by comparing the observed data against the simulated ones by the model. If the value of the function is above the prescribed tolerance value, the process is continued iteratively through computing a correction to the parameters by using an optimization. In this study Powell's optimisation algorithm (Press *et al*. 1992 p. 409) is applied. The advantage of using this algorithm is that it does not need to calculate the derivative of the objective function. The roughness identification procedure is illustrated in Figure 1.

The selection of objective functions is one of the factors affecting the quality of identification problem. Nguyen and Fenton (2004) investigated the effect of three main types of objective function and showed that least square objective function had the best performance. Khabiti *et al*. (1997) indicated that the selection of objective function was found to be prone to undue biases affecting the identified parameters, which could be avoided through a careful consideration of the problem. They considered the sum of square of errors using absolute errors and relative errors with respect to observed values and relative errors with respect to simulated values. They concluded that the formulation of the objective function using relative errors seems to induce an undue bias that increase with increasing noise level. Therefore, in this study the objective function sum of square of absolute errors between observed and simulated stages/discharges is considered as follows:

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

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

In this study, the roughness coefficients of main channel and flood plains will be considered as constants as well as second order polynomial functions of water stage as follows:

For main channel roughness:

$$n_c = a_0 + a_1(Z - Z_0) + a_2(Z - Z_0)^2 \tag{6}$$

For main floodplains roughness:

$$n_f = b_0 + b_1(Z - Z_f) + b_2(Z - Z_f)^2 \tag{7}$$

where: n_c and n_f are roughness coefficients of main channel and floodplains respectively, Z is the water stage, Z_0 is the minimum water level at a certain cross section at which the cross section characteristics are start tabulated in the input data, Z_f is elevation of floodplains, and a_0, a_1, a_2, b_0, b_1 and b_2 are coefficients of the roughness function that need to be identified.

3. CASE STUDY

The model for identification of roughness coefficients was applied to the Duong River in Red River delta, Viet Nam. The river is one of the main distributaries of Red River that conveys the water from Red River to Thai Binh River. The computed reach is 61.71 km long from Thuong Cat to Pha Lai. There are 3 gauging stations along this reach: Thuong Cat, Ben Ho and Pha Lai (see figure 2). The discharge hydrograph at Thuong Cat was chosen as the upstream boundary condition and the stage hydrograph at Pha Lai was chosen 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 September, but usually the flood plains are flooded from middle of July to end of August.

Cross section data were obtained from the Institute for Water Resources Planning and Management (Viet Nam) which were surveyed in the dry season in 1996. There were 33 cross sections measured along the river. The cross sections of this river are compound cross sections including of main channel and flood plains with their widths ranging from 300 to 2000m with different water levels.

The slope of the river is very flat with the average slope is 0.0001 or 10cm/km. The roughness conditions of main channel and flood plains are different. The main channel is an alluvial channel while the floodplains have bushes, trees and small houses. Because the roughness conditions are similar along the computed reach and there is one gauging station at Ben Ho as observation data that can be used to identified the roughness therefore, in this study, the roughness coefficients of the main channels and flood plains are considered as constants for the whole reach. Different flood events which occurred during the validity of the cross section survey will be considered.

4. RESULTS AND DISCUSION

The performance of the model was evaluated for different flood events in term of sizes of peak discharges and flooding levels. Five recent flood events were chosen in the years of 1995, 1996, 1997 and 1998 to identify the roughness coefficients of the main channel and floodplains. Firstly, the roughness in main channel is identified using the events before the floodplain is inundated. Then the flood plain roughness is identified using different flood events are shown in Table 1 below. Figure 3 shows the stage hydrographs at Ben Ho as well as Thuong Cat where the water elevation data at this gauging station was not included in the objective function during optimization. This can be used to verify the quality of identified parameters. From the figure it can be seen that the simulated stage hydrographs using identified roughness coefficients are matched quite well to the observed ones for all the flood events at this gauging station. The computed results show in Table 1 indicates that the identified roughness coefficients for the main channel (n_c) and floodplains (n_f) ranged from 0.0302 to 0.0340 and from 0.0554 to 0.0622 respectively for different flood events and different years. From the table, it can seen that the roughness values changed with time not only from year to year and but also during each flood season, for example the roughness coefficients for two events 20/7-30/7/1996 and 16/8-31/8/1996. This variation can be attributed to the characteristics of alluvial channels and/or errors in observation data. However, the identified roughness coefficients are rather consistent in a certain range.

One observation from the computed results is that the values of roughness in floodplains are smaller at lower water stage. This may be attributed to the variation of roughness with stage. In order to see the performance of the model in the in the case when the roughness coefficients are functions of water stage the flood event from 16/8-31/8 was chosen to identify the values of roughness as functions of stage where the roughness values of main channel and floodplains as Eqs. (4) and (5). The identified coefficients a_0, a_1, a_2, b_0, b_1 and b_2 are 0.0315, 6.17E-05, 4.32E-06, 0.0552, 1.59E-03 and 1,04E-04 respectively. So for this event, the roughness values in main channel and floodplains at Ben Ho ranged from 0.0320 to 0.0324 and from 0.0552 to 0.0609 respectively. The results indicate that the main channel roughness values are almost constant while the floodplain roughness values change rather more with stage. The study also found that when identifying roughness coefficient as functions of stages the number of identified parameters increases causing the computation time increase considerably. For example for this case study, the computation time is about four times in comparison with the case where the roughness coefficients are considered as constants.

Table 1: Identified roughness coefficients for Duong River from different flood events

Flood event	Observed peak discharge at Thuong Cat (m^3/s)	Observed peak stage at Ben Ho* (m)	Identified main channel roughness n_c	Identified floodplain roughness n_f
14/8-31/8/1995	5650	8.58	0.03322	0.06223
20/7-30/7/1996	5020	7.78	0.03019	0.05739
16/8-30/8/1996	6120	9.02	0.03149	0.06004
22/7-6/8/1997	4870	8.06	0.03399	0.06194
26/7-5/8/1998	4910	7.42	0.03365	0.05535

Note: * the starting flood plain elevation at Ben Ho is 6.0 m

5. CONCLUSIONS

In this study, the inverse problem of identifying roughness coefficients has been extended to compound channels. The study was applied to a natural channel with compound cross sections of the Duong River in the Red River delta, Viet Nam, where the values of roughness in the main channel and flood plains were identified. The performance of the model was evaluated for different flood events in terms of sizes of peak discharges. The results indicate that the values of roughness values in main channel and floodplains of the river change with time but they are rather consistent within reasonable ranges. The variation of roughness coefficient with water stage was also considered, where the roughness functions were formulated as second order polynomial functions of water stage. The performance of the model indicates the ability to apply the problem to natural channels.

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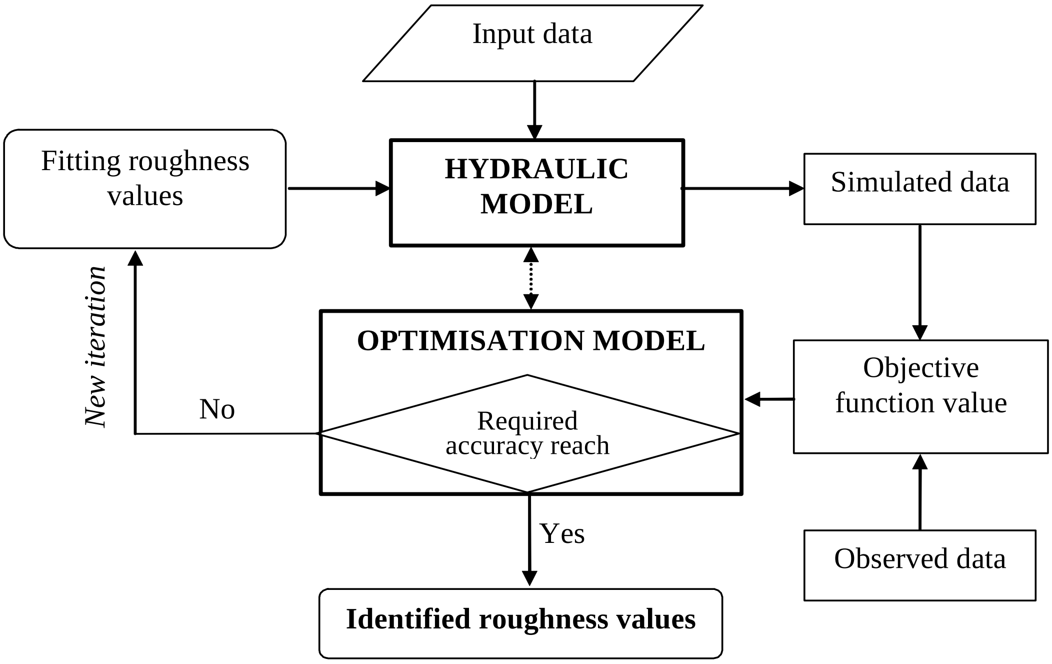


Figure 1 The roughness identification procedure

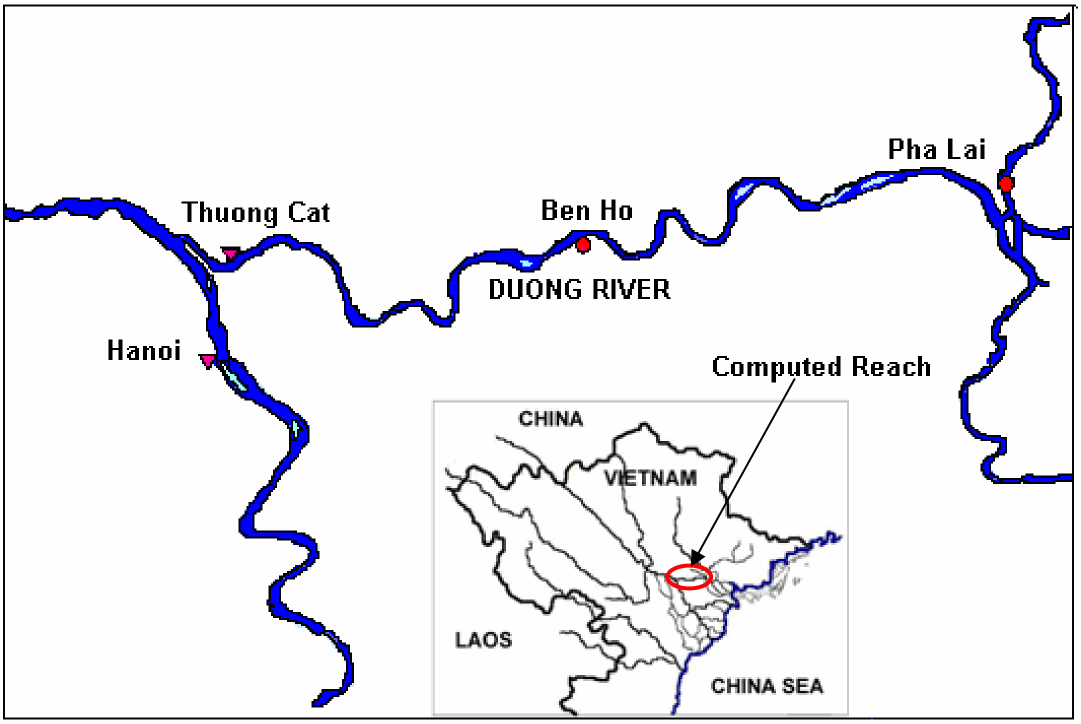
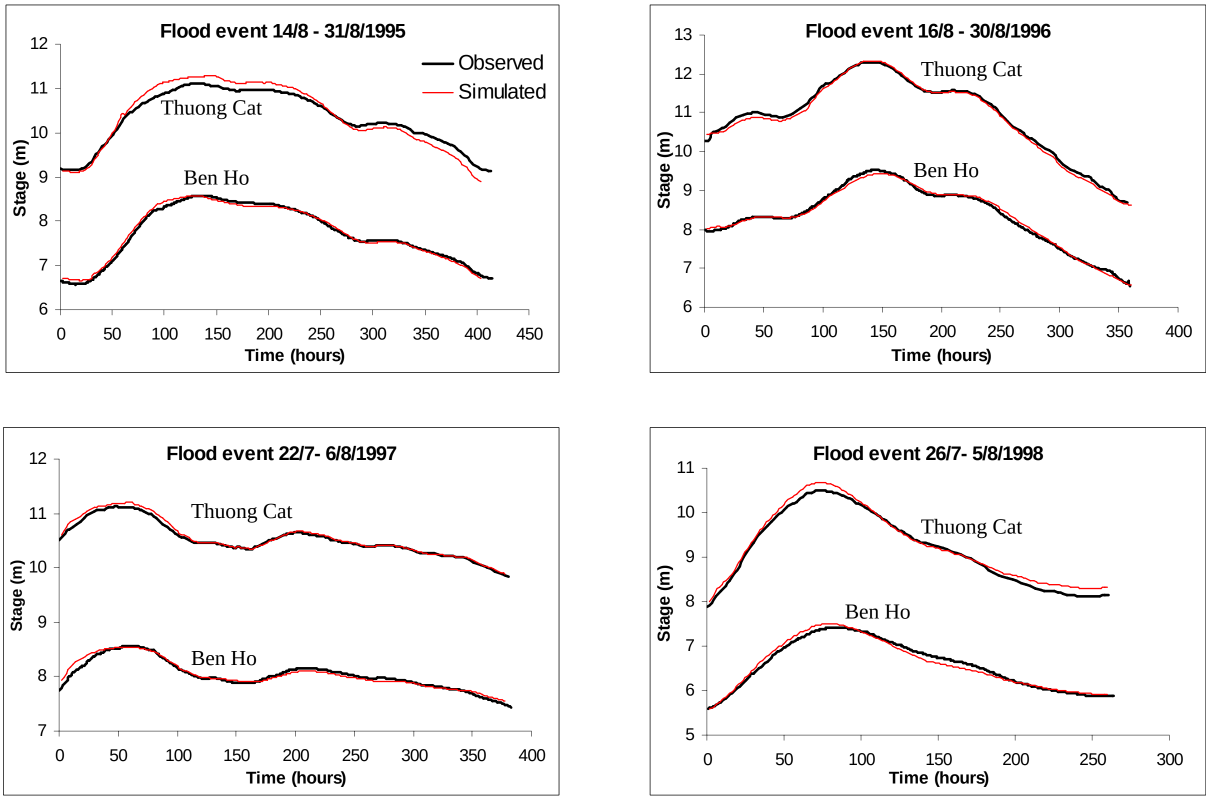


Figure 2 Duong River and the Gauging Stations along the river.


Flood event 14/8 - 31/8/1995

Flood event 16/8 - 30/8/1996

Flood event 22/7- 6/8/1997

Flood event 26/7- 5/8/1998

Figure 3 Observed and simulated stage hydrographs at Ben Ho and Thuong Cat for different flood events using the identified roughness values