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RIVER CONFLUENCES ON ALLUVIAL STREAMS WITH EQUAL DISCHARGE AND EQUAL BED WIDTHS

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The experiment for river confluences on alluvial streams at 45^0 are undertaken. Two models with different conditions are carried out. Suitable mathematical models to simulate river confluence problems are designed. The experiment data are used to calibrate the mathematical models. The flow pattern, flow velocity vectors and bed configuration especially at the confluence region are studied comparatively with the experiment results. Each term of momentum equation for both fixed flat and movable bed are investigated along the main channel. The effect of eddy viscosity on flow pattern on the right side of main channel at the junction is considered. Finally satisfied results and good agreement between physical and numerical models are gained.

Keyword: River confluences, bed evolution, momentum equation terms and rise of water surface.

1. INTRODUCTION

The hydraulic characteristics at the point of river confluences are influenced by the channel alignment and the downstream flow hydraulic conditions, after mixing of two flows to form a single river channel. This situation appears in every river system. It occurs in a comparatively short river length and is characterized by bed scour, bank erosion, bar formation and rise of water surface. Therefore, confluences are critical elements in a river system and the understanding of these facts is essential in flood control, irrigation systems, sewage systems, navigation and etc. The studies of river confluences have been done by many researchers for the view of different specified points[6-9]. But in those papers, the width of tributary channel is too small comparing to main channel.

In the present contribution, the authors attempt to simplify confluence flow experimentally and analytically. The confluent channels are the same width and same discharge as mentioned [1]. The simulation results are compared with the experiment results. Magnitude of each term of the momentum equations calculated analytically with rough fixed bed and rough movable bed after stability are considered. The main objectives in the current study are: 1) Trying to yield a suitable mathematical model to simulate the river confluence problems. 2) Reporting an extensive testing of the mathematical model by comparing with the physical model. 3) Studying the bed configuration and flow pattern under different conditions. 4) Studying each term in the momentum equation.

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2. EXPERIMENTAL PROCEDURE

The main channel is 5.0m long and the tributary channel is 2.10m long. The cross-section for both main and tributary channels are 0.2m wide and 0.2m height. The confluence angle is fixed 45^0 as shown in Fig.1. The joint at the bed is smooth and plane whereas joints at the wall are sharp and vertical.

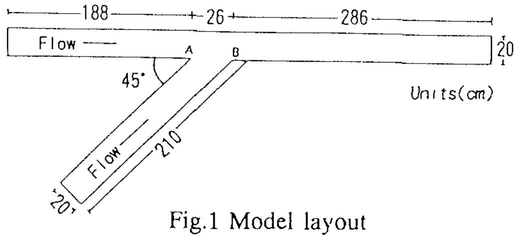


Fig.1 Model layout

The present study contains two models: I) Rigid rough bed with slope 1/500 and Manning resistance coefficient (n=0.008). II) Movable rough bed with slope 1/500, n=0.022 and mean bed material (d_m=0.6mm). The flume is operated successfully, the discharge ratio($Q_{tributary}/Q_{total}$) is 0.50 and the total discharge is 2 l/s. The measurements of longitudinal and lateral velocities are carried out by an electromagnetic current meter utilizing an AD converter. Water surface and water depth in model I are measured by using TEAC DRF1 digital recorder but in model II point gage is used. In model II the flume is completely drained after reaching equilibrium condition of bed sediment and the bed configuration is observed. After fixing the bed and flowing the water, flow velocity vectors and water depth are measured.

3. NUMERICAL METHOD

3.1 ASSUMPTIONS

a) The channels shape are rectangular. b) No source for feeding sediment, Q_{sed} input is zero. c) Water viscosity is constant. d) The flow passing through the flume is subcritical. e) Ordinary wall friction is negligible in comparison with other forces involved.

Boundary conditions are: Water depth at the downstream end (h_{downst}) and Water discharge at the upstream end (Q_{upst}) are determined (from experiment).

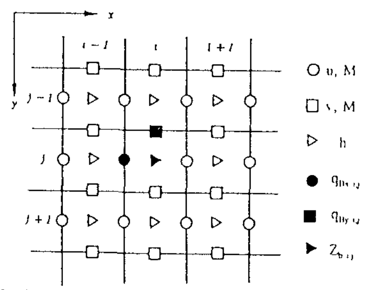


Fig.2 Arrangement drawing for calculating items of flow and bed variation

3.2 BASIC EQUATIONS AND SIMULATION METHOD OF FLOW FIELD

The 2-dimensional equations of flow are described as follows, using cartesian coordinate system as shown in Fig.2.

In order to tend the true solution (high accuracy), minimizing the truncation error at the same time keeping the stability are considered as follows:

a) Δt and $\Delta x \rightarrow 0$ (the truncation error goes to zero). b) The condition of stability a "Courant-Friedriches-lewy condition" or simply "C.F.L condition" is applied

Therefore, Δx_{min} =2cm, Δy =2cm and Δt =0.002 sec are chosen.

Continuity Equation of Flow

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \quad (1)$$

Momentum Equation of Flow

$$\frac{\partial M}{\partial t}+\frac{\partial}{\partial X}(uM)+\frac{\partial}{\partial y}(vM)=-gh\frac{\partial H}{\partial X}-\frac{\tau_{bx}}{\rho}+\bar{\varepsilon}\frac{\partial^2 M}{\partial x^2}+\bar{\varepsilon}\frac{\partial^2 M}{\partial y^2} \quad (2)$$

$$\frac{\partial N}{\partial t}+\frac{\partial}{\partial X}(uN)+\frac{\partial}{\partial y}(vN)=-gh\frac{\partial H}{\partial y}-\frac{\tau_{by}}{\rho}+\bar{\varepsilon}\frac{\partial^2 N}{\partial x^2}+\bar{\varepsilon}\frac{\partial^2 N}{\partial y^2} \quad (3)$$

where M and N are discharge flux(= uh and vh) respectively; h is water depth; H is water surface elevation; g is gravity acceleration; u and v are depth average velocities in x and y direction respectively; τ_{bx} and τ_{by} are bed shear stress in x and y direction respectively and the value of momentum correction coefficient is assumed to be unity in equations (2) and (3).

$$\frac{\tau_{bx}}{\rho}=\frac{gn^2 u\sqrt{u^2+v^2}}{h^{1/3}}, \quad \frac{\tau_{by}}{\rho}=\frac{gn^2 v\sqrt{u^2+v^2}}{h^{1/3}} \tag{4}$$

where n is Manning roughness. $\bar{\varepsilon}$ is the depth averaged value of vertical eddy viscosity coefficient

$$\bar{\varepsilon}=\frac{1}{h}\int_0^h \varepsilon\, dy=\frac{1}{6}\kappa u_* h=0.067u^* h \tag{5}$$

where κ is von Karman's constant (κ=0.40); u_* is the friction velocity and h is the depth of flow.

3.3 BASIC EQUATIONS AND SIMULATION METHOD OF BED EVOLUTION

The continuity equation for 2-dimensional bed load transport for uniform bed materials is described as follows:

$$\frac{\partial Z}{\partial t}+\frac{1}{1-\lambda}\left(\frac{\partial q_{Bx}}{\partial x}+\frac{\partial q_{By}}{\partial y}\right)=0 \tag{6}$$

where Z is bed elevation; λ is the porosity of bed materials; q_{Bx} and q_{By} are bed load transport in x and y directions respectively.

The bed load transport rate in longitudinal direction q_{Bx} is calculated on the basis of equation which was proposed by Ashida and Michiue [3] and it is expressed by the following equation:

$$\frac{q_{Bx}}{\sqrt{sgd^3}}=17\tau_{*e}^{3/2}\left(1-\frac{\tau_{*c}}{\tau_*}\right)\left(1-\sqrt{\frac{\tau_{*c}}{\tau_*}}\right) \tag{7}$$

The bed load transport rate in transverse direction q_{By} is calculated by the equation proposed by Hasegawa [4] as follows:

$$q_{By}=q_{Bx}\left(\tan\delta-\sqrt{\frac{\tau_{*c}}{\mu_s\mu_k\tau_*}}\frac{\partial Z}{\partial y}\right) \tag{8}$$

where s is relative density of bed material; d is the diameter of bed material; τ_* is non -dimensional bed shear stress; τ_{*e} is non-dimensional effective bed shear stress; δ is the angle between the velocity components in x and y direction (δ = arctan (v/u)); μ_s is the static friction factor (=1.0)and μ_K is the kinematic friction factor (= 0.5).

In the present study, using eq.(1) to eq.(8), the two-dimensional flow and bed elevation are calculated by means of numerical method proposed by Fujita et al.[5].

4. RESULTS AND DISCUSSIONS

4.1 MODEL I (rough fixed bed)

(A) Water Depth: Fig.3 shows the longitudinal water profile at left, middle and right side of the main channel. In those figures, A and B indicate the confluence points as shown in Fig.1. We focus on the following two points. The first, according to the principal problem of combining flow, when two streams combine in a single channel, the depth just downstream the junction will be fixed by back water characteristics of the channel and the magnitudes of combined rate flow. One should normally expect the critical flow conditions to occur at the section of maximum contraction. However, the flow is truly three-dimensional in the contraction region. Nevertheless, the flow quickly tends to regain its one-dimensional nature after it reattaches to the side wall of the main channel at a certain distance from down stream junction. This phenomena appeared clearly by sudden drop with maximum value on the right side followed by rising up in the water surface as shown in Fig.3. The second is the depth rise just upstream the junction. By inspecting the results shown in Fig.3, we can say that we have a good agreement for both experimental and analytical results.

(B) Flow Velocity Vectors: From physical and analytical results as shown in Fig.4, we can see that the influence of main and tributary channel on each other is almost equivalent and the streamline of the separation zone reaches till the middle of main channel. The relation of average flow velocities is in a good agreement except one point downstream the confluence on the right side of main channel as shown in Fig.4. The difference might be caused because of the sharp-edged flume side wall at the junction.

(C) Momentum Equations: In order to consider the characteristics of water depth and flow velocities more detail, we investigate the balance of momentum equation in x-direction of main channel. Fig.5(a) to (c) show the magnitude of each term of momentum equation at left, middle and right side of main channel. In the left side of main channel,we can find that the convection term in x-direction(A1) start to increase its value in positive side to have balance with the convective term in y-direction (A2) and the pressure gradient (A3) in negative side. Those three terms reach their maximum values just down stream the junction, where the conditions of existence of critical section depend on many variables such as discharge ratio, Froude Number, the junction angle, junction energy loss and channel slopes. However, the discharge ratio is the most important variable. It controls the contraction of flow in the main channel to large extent [2]. After reaching the maximum value those three terms (A1,A2 and A3) tend to decrease till they vanished at 1.5 junction length downstream. The other terms play insignificant role. The second is various terms at middle of main channel. The pattern of each term on the middle side repeated with maximum value 1.5 time of the left side. The affected zone slightly shifted toward upstream, as shown in Fig.5(b). The third is the right side of main channel. The situation is more complicated than others. At the beginning of the junction, A1 start to increase to have balance with A2 and A3, (A1=A2+A3). A1 gradually decreased and suddenly increased to maximum negative value, A2 reverse to positive side and diffusion term in y-direction (A6) appeared to have balance with A3 which sharply increased to maximum and the diffusion term in x-direction (A5), (A3+A5=A1+A2+A6). After short distance A6 vanish and A5 reverse, (A3=A1+A2+A5). A2 again reversed to negative side to alternate with A3 and A5, (A1+A5=A2+A3). The affected zone contracted more and its length is only about 0.3 time of the junction length. By looking carefully we found that although diffusion terms A5 and A6 have only appeared at the downstream of confluence B in the right side of main channel with small value comparing to other terms, but they play a significant role in decreasing water depth and size of the separation zone at the confluence region which make it more close to the experiment results. Fig.6 which is calculated without diffusion terms A5 and A6 could be compared with Fig.3(b) to see the difference.

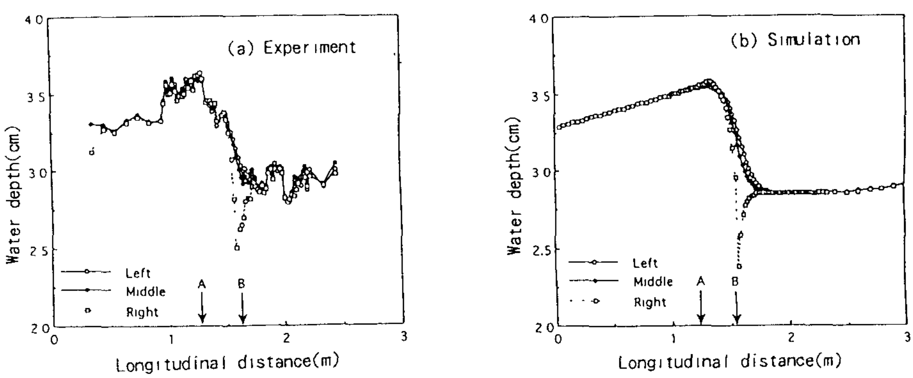


Fig.3 Longitudinal water profiles (Model I)

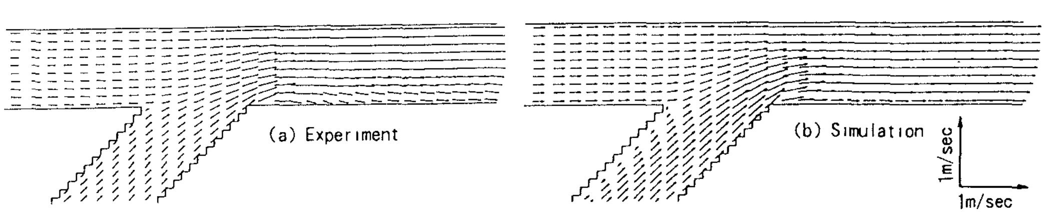
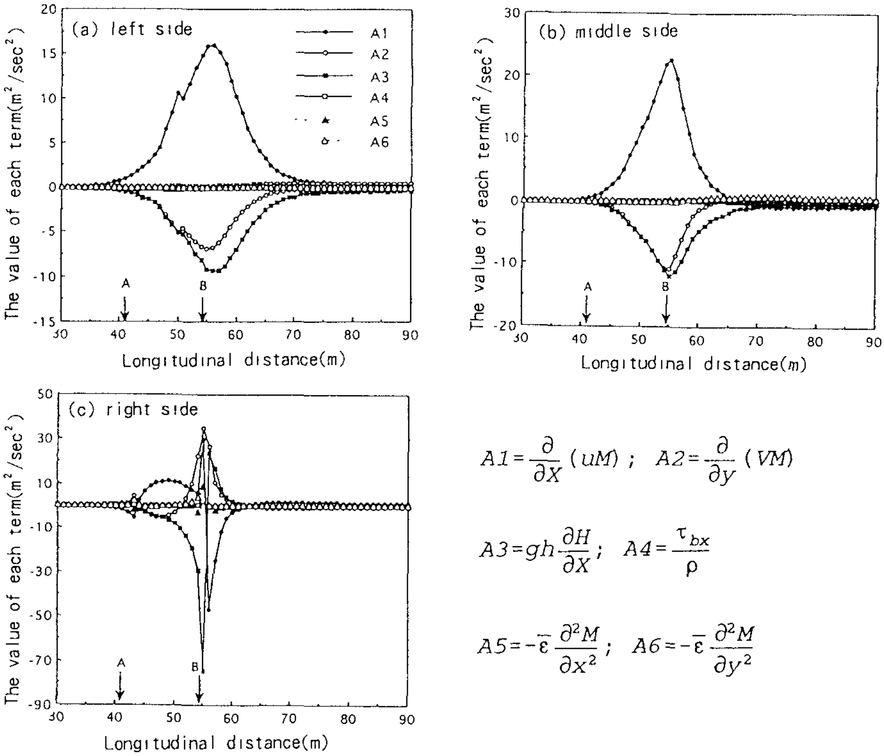


Fig.4 Averaged flow velocity vectors (Model I)



$$A1=\frac{\partial}{\partial X}(uM)\ ;\quad A2=\frac{\partial}{\partial y}(VM)$$

$$A3=gh\frac{\partial H}{\partial X};\quad A4=\frac{\tau_{bx}}{\rho}$$

$$A5=-\bar{\varepsilon}\frac{\partial^2 M}{\partial x^2};\quad A6=-\bar{\varepsilon}\frac{\partial^2 M}{\partial y^2}$$

Fig.5 Balance of momentum equations (Model I)

4.2 MODEL II (rough movable bed)

(A)Water depth: The water depth along the main channel appeared to be uniform as shown in Fig.7. This might be caused by the effect of scour holes happened at the confluence and its downstream. A good agreement between the experiment and analytical results is gained.

(B) Flow velocity vectors: Fig.8 shows the flow velocity vectors for experiment and simulation. The relation of averaged velocities between them is in good agreement except one point just downstream the confluence on the right side of main channel as shown in Fig.8. This might be caused because of the same reason in model I. By comparing the average velocity in both model I and model II, we can see that the amount in model II decreased especially downstream of the junction because of the bed degradation.

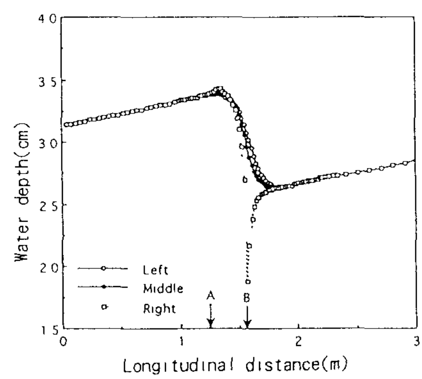


Fig.6 Longitudinal water profiles

(C)Bed topography: At the beginning of experiment, flow was over the flat bed and thus a flow pattern similar to Model I was observed. The flow pattern changed very fast to appear bed scouring just the downstream corner (point B in Fig.1). The recirculation zone became smaller due to the deposition of sand by secondary flow. With time, scour hole gradually moved towards the center of main channel. Fig.9(a) shows the bed configuration after equilibrium condition of sediment. Two scour regions occurred. The first one occurred just downstream the confluence where the velocity accelerated. The second one occurred on the left side of main channel where the influence of the tributary channel reached. Maximum scour depth with mathematical model was rather less in amount than the physical model, but the region of occurring bed variation was almost the same as shown in Fig.9(b).

(D) Momentum equations: Three longitudinal profiles as the same as in model I are shown in Fig.10. In the first, A1 balances with A2 and A3 (A1=A2+A3).The maximum values of A1 and A2 reduced into (0.4) times of that in model I. A3 reduced to much, that is because of the uniformity of flow which reduced

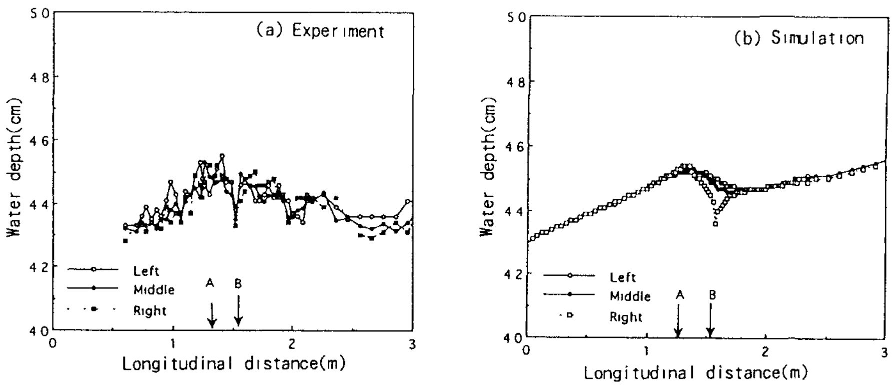


Fig.7 Longitudinal water profiles (Model II)

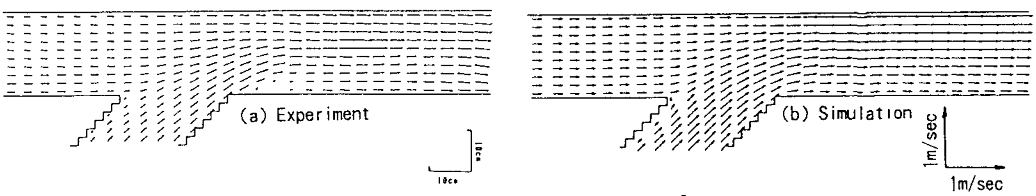


Fig.8 Averaged flow velocity vectors (Model II)

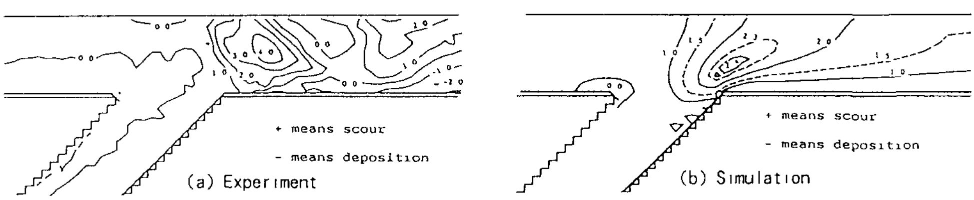


Fig.9 Bed configuration

gravity acceleration and increasing water depth which cause decreasing on convective terms A1 and A2. The second is the middle of main channel. The same situation which happened in left side repeated. A1, A2 and A3 are as the same shape as in left side but their values decreased into (0.3 to 0.4) times of that in model I. The affected zone tends to move upstream which is the same as model I. The third is the right side of main channel. The complexity is as the same as in model I but the maximum values reduced into (0.3 to 0.4) time of model I. The effected zone downstream also tends to upstream.

5. CONCLUSION

Throughout the results discussed in the present study, we think that fairly agreement between physical and mathematical model is achieved. Accordingly we might say that the numerical model could be available for more applications in the field of hydraulic and alluvial rivers.

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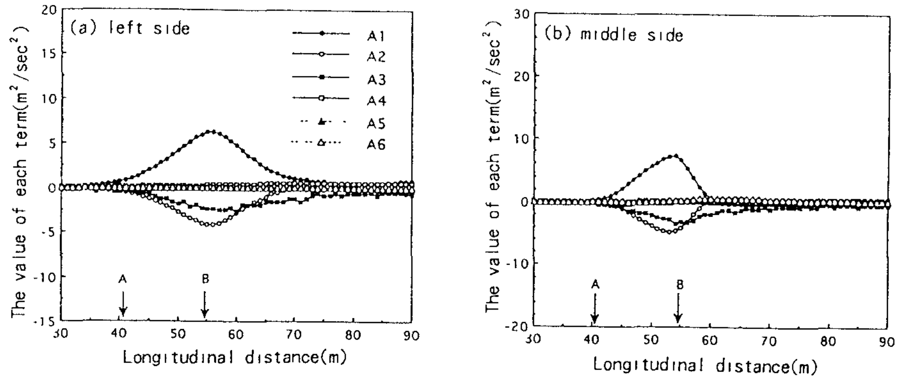

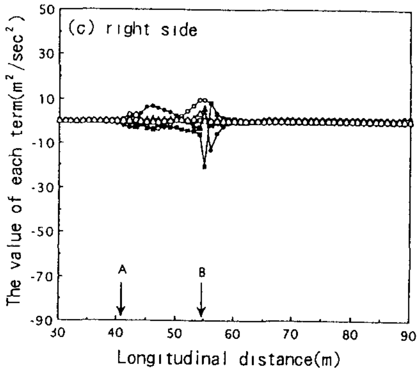

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Fig.10 Balance of momentum equations (Model II)

REFERENCES

1- Ahmed A. Rady, Michue, M. and Hinokidani, O.(1995). "River confluences on alluvial streams at 45-degree". Proceeding of the 50th annual conference of the JSCE, Sept., pp 452-453.

2- Ameuthur S. Ramamurthy, Luis B. Charballada (1988)." Combining open channel flow at right angled junctions", Journal of ASCE, vol.114, no.12, pp.1449-1460.

3- Ashida, K. and Michiue, M. (1972). "Study on hydraulic resistance and bed load transport rate in alluvial streams" , Proc. JSCE No.206, pp., 59-69, (In Japanese).

4- Hasegawa, K. (1981). "Bank erosion discharge based on non-equilibrium theory", Proc. JSCE, Vol.316,pp.37-50. (In Japanese).

5- Fujita, M. and Michiue, M. (1984). " River bed erosion by meandering streams. proceeding, 9th congress of APD, pp.344-351.

6- James L. Best (1988). "Sediment transport and bed morphology at river channel confluences". Sedimentology, 35, pp481-498.

7- L. Cheng, S. Komura and I. Fujita (1992). "Numerical simulation of the confluence flow by using κ-ε models". Proceeding of hydraulic engineering, JSCE, Vol.36, pp.169-174.

8- S. B.Weerakoon, T. Imasato, Y.Kawahara,N. Tamai and Y. Hirosawa (1989)." Flow measurements at 60-degree confluences". Proceeding of the 44th annual conference of the JSCE,2, Oct., pp 406-407.

9- S. B.Weerakoon, N. Tamai and Y.Kawahara (1990). "Bed topography bed shear stress distribution and velocity field in a confluence. "Proceeding of hydraulic engineering, JSCE, Vol.34, pp.307-312.