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BED VARIATIONS DURING THE 1981-FLOOD IN THE LOWER ISHIKARI RIVER

by

Yasuyuki Shimizu
Tadaoki Itakura

Civil Engineering Research Institute, Hokkaido Development Bureau
Sapporo, Hokkaido, 062, Japan

Tsutomu Kishi
Mikio Kuroki

Department of Civil Engineering, Faculty of Engineering
Hokkaido University, Sapporo, Hokkaido, 060, Japan

SYNOPSIS

A detailed observation of a flood was performed in the Ishikari River in August 1981. The observation includes the measurements of flow rate, water surface elevation, sediment transport rate, resistance to flow and bed configuration of the river channel. The bed topography before and after the flood is compared each other in a reach of the river channel between the river mouth and 8*km* upstream. It was found that the geometrical characteristics of the river channel and hence the hydraulic roughness depend on the hydraulic quantities of the flow, but these flow properties were in turn strongly dependent on the channel configuration and its hydraulic roughness. A one-dimensional numerical simulation model to predict the bed variation is proposed taking into account the variation of the hydraulic roughness and the transport rate of suspended sediment. The calculations were compared with the field observations, and good agreements were observed.

INTRODUCTION

In planning an improvement of river channels, it is necessary to predict the bed variations and to investigate the river channel itself during floods.

The Ishikari River is the third longest river in Japan. Its length is 268*km* through the drainage area of 14,330km^2. In August 1981, the Ishikari River had a heavy rainfall caused by a typhoon and a cold front. The total amount of rainfall was 282*mm* as an averege in the river basin. It caused the greatest flood since the gauging stations started to operate in 1878. The water surface elevation at the Ishikari-Ohashi gauging station was 9.23*m* at 02:00 on August 6 which was higher than a design high water level of 8.25*m* at that time.

Extensive observation of the 1981-flood was performed by the Hokkaido Development Bureau. A general description of the flood observations has been reported by Takagi et al. (13) and the organization for the measurement has been documented by Hoshi et al. (3). Itakura et al. (7) reported an analysis of bed topography and resistance to flow during the flood.

This paper introduces a part of field observations and theoretical studies of river channel in the lower Ishikari River, where sudden expansion, sudden contraction and a bend are present. An analysis of the bed topography is performed, and an attempt is made to calculate the bed variation taking into account a change of resistance to flow during the flood.

BED VARIATION DURING FLOOD

Observations of the bed topography were performed before the flood in May 1981 and just after the flood in August 11, 1981. Some examples of the cross sections are shown in Figs. 1 to 4, in which rigid curves are of May and dashed curves are of August, respectively, and x=distance from the river mouth. The observations in May 1981 were carried out just after a snow melt runoff, and since that time there was not any remarkable runoff untill the 1981-flood. Therefore, the cross sections in May 1981 can be regarded almost identical with those before the 1981-flood.

Fig. 1 shows the cross section at the river mouth, in which it is revealed that the channel bed was eroded about 8*m* during the flood and the cross sectional area was increased about 1,000 m^2. Much the same degradations of the bed were observed in a reach between the river mouth and 8*km* upstream and a large amount of bed materials was found to be flushed out into the sea.

In Figs. 2 and 3, circles are quated from the measurements of longitudinal bed profiles (7) performed during the flood on August 7 at the time denoted on the hydrograph shown in Fig. 5. Futher degradation of about 1 *m* was observed in the midst of the flood in Figs. 2 and 3.

The measurement of cross section was performed at each station 200*m* apart each other before and after the 1981-flood. A longitudinal distribution of the increment of the cross sectional area, ΔA, at each station is depicted in Fig. 6. The largest increase of the cross sectional area is

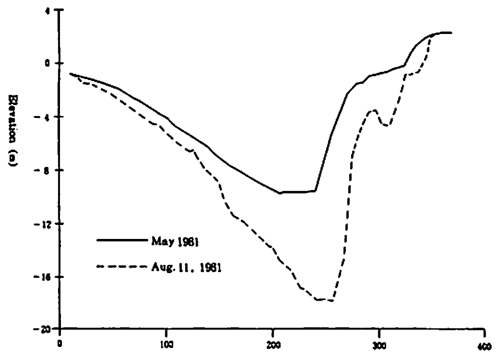


Fig. 1 Cross section at x=0

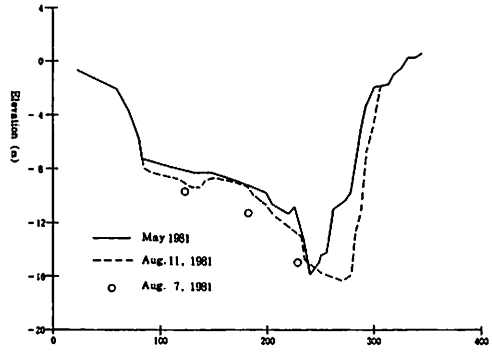


Fig. 2 Cross section at x=2.5*km*

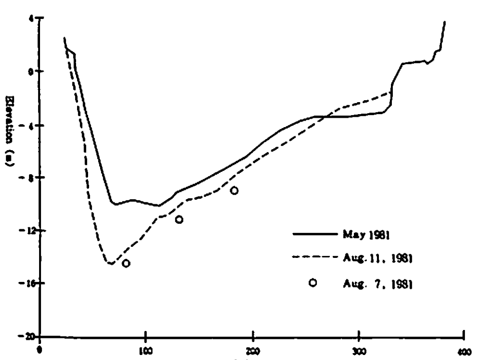


Fig. 3 Cross section at x=3.5*km*

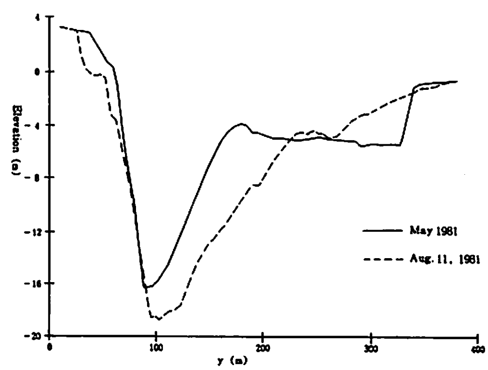


Fig. 4 Cross section at x=5.0*km*

observed at the Kakokyo Bridge due to erosions around its bridge piers. The second one is observed around the river mouth, which is caused by a steeper water surface slope and larger bed shear stress as analysed by Itakura and Kishi (6). From Fig. 6 it is evaluated that the total amount of 2.8 million m^3 bed materials was flushed out from the river into the sea.

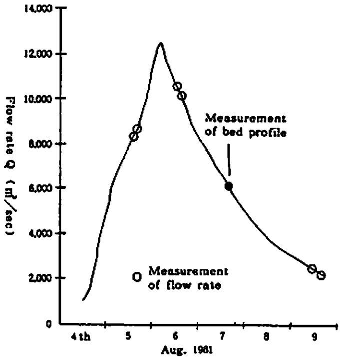


Fig. 5 Hydrograph of the 1981-flood

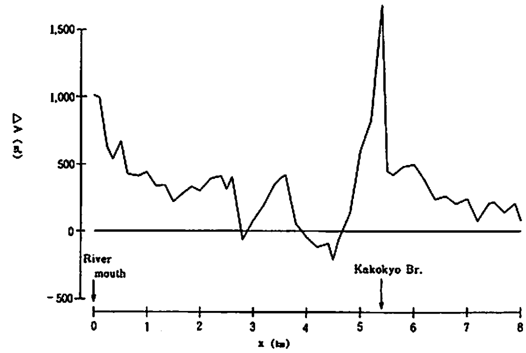
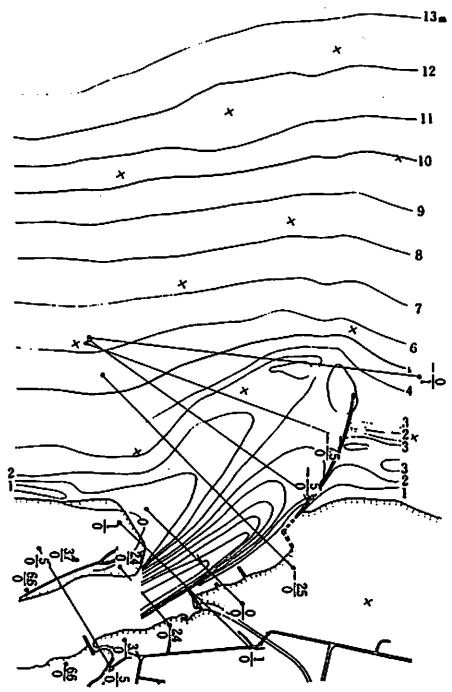


Fig. 6 Increment of cross sectional area

Figs. 7 and 8 show contour maps of the sea botom in July and August 1981, respectively. Before the 1981-flood, the sand particle discharge from the river is supposed to be transported by littoral currents and the contour lines run almost parallel to the coast line as shown in Fig. 7. On the other hand, after the flood the bed topography is characterized by a deep scour along a jetty located at the right bank and a lingual shaped sand deposition extending more than $2km$ into the sea as shown in Fig. 8. It is found by comparing Figs. 7. with 8 that 3.3 million m^3 sand deposited in front of the river mouth.



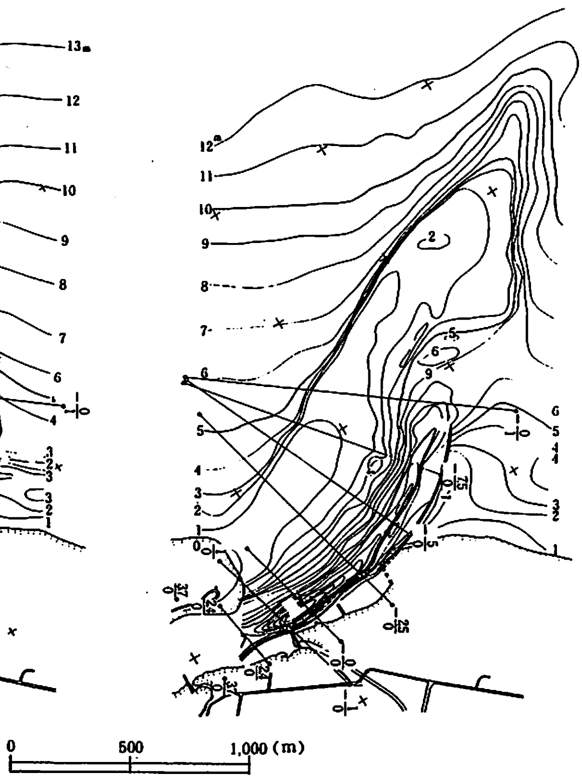


Fig. 7 Bed topography around river mouth, July 1981

Fig. 8 Bed topography around river mouth, Aug. 1981

CALCULATION OF BED VARIATION

It has been recognized by the observations of sediment transport rate in this reach of the Ishikari River that the bed material consists of very fine sand and the suspended sediment predominates in the bed material load. An attempt is made to evaluate the bed variation using one-dimensional simulation model taking into accout the sediment transport of the suspended load.

Basic equations

Equation of motion for flow;

$$\frac{\partial}{\partial x}\left(H+\frac{\alpha Q^2}{2gA^2}\right)+I_e=0 \tag{1}$$

Equation of continuity of sediment transport;

$$\frac{\partial z}{\partial t}+\frac{1}{1-\lambda}\left[\frac{1}{B}\frac{\partial(q_{BT}B)}{\partial x}+\sum_i(q_{sui}-W_iC_{bi})\right]=0 \tag{2}$$

Equation of continuity of sediment tranport of each fraction, i, of nonuniform bed material;

$$\delta\frac{\partial P_i}{\partial t}+P_{i*}\frac{\partial z}{\partial t}+\frac{1}{1-\lambda}\left[\frac{1}{B}\frac{\partial(q_{Bi}B)}{\partial x}+q_{sui}-W_iC_{bi}\right]=0 \tag{3}$$

where

$$P_{i*}=\begin{cases}P_i & for\quad dz/dt\geqq 0\\ P_{i0} & for\quad dz/dt<0\end{cases}$$

Equation of continuity of suspended sediment;

$$\frac{\partial(\bar{C}_ih)}{\partial t}+\frac{1}{B}\frac{\partial(Q\bar{C}_i)}{\partial x}=q_{sui}-W_iC_{bi} \tag{4}$$

where

$$\bar{C}_i=\frac{1}{h}\int_0^h C_idz=\frac{C_{bi}}{\beta}(1-e^{-\beta})$$

$$\beta=\frac{W_ih}{\varepsilon},\quad \varepsilon=\frac{\kappa}{6}U_*h$$

in which x=coordinate in direction of flow; H=water surface elevation; Q=flow rate; A=cross-section area of flow; g=acceleration due to gravity; I_e=slope of energy gradient; z=bed surface elevation; t=time; λ=porosity of sediment; B=width of channel; q_{BT}=total bed load transport rate per unit width (=Σq_{Bi}); q_{Bi}=bed load transport rate per unit width of fraction i; C_i =volumetric concentration of suspended sediment of fraction i at z; C_b=reference concentration; δ=thickness of exchange layer of bed; P_i, P_{i0}=fraction of sand particle of diameter d_i in and below the exchange layer, respectively, q_{sui}=rate of detachment of suspended sediment from unit area of bed surface; h=depth of flow; W_i=fall velocity of sediment of fraction i; ε=diffusion coefficient; κ=von Karman constant (=0.4); and U_*=shear velocity (=$\sqrt{(ghI_e)}$).

Calculations of the bed load transport rate in Eq. 2 are performed using Eq. 5, which was proposed originally by Sato, Kikkawa and Ashida (10) and modified for the mixture of sizes by Hirano (2).

$$\frac{q_{Bi}}{\sqrt{sgd_i^3}}=P_i\cdot\phi\cdot f\left(\frac{U_{*ci}^2}{U_*^2}\right)\cdot\tau_{*i}^{\frac{3}{2}} \tag{5}$$

in which ϕ= 4 ; s=specific weight of bed material in water; τ_*=dimensionless bed shear stress (= hI_e/sd); and U_{*ci}=critical friction velocity of franction i in a mixture of bed materials, and is calculated from Eq. 6 which was proposed by Asada (1).

$$\frac{U_{*ci}^2}{U_{*cm}^2} = \left[\frac{\log 23}{\log(21\frac{d_i}{d_m} + 2)}\right]^2 \frac{d_i}{d_m} \tag{6}$$

in which d_m=mean diameter of bed material; U_{*cm}=critical shear velocity for particle of mean diameter and was calculated from equations presented by Iwagaki (8). The rate of detachment of suspended sediment, q_{sui}, was calculated from equations proposed by Itakura and Kishi (4 and 5).

Friction factor and computation of water surface elevation

The geometrical characteristics of the channel bed and the hydraulic roughness depend on flow properties in this reach of the Ishikari River and these flow properties are in turn dependent on the channel configuration and its roughness, as reported by Kishi and Kuroki (9). Relationships between τ_* and grain shear stress, τ_*', are shown in Fig. 9 in which each plot corresponds to each circle on the hydrograph of the 1981-flood shown in Fig. 5. The grain shear stress is calculated by Eqs. 7 and 8.

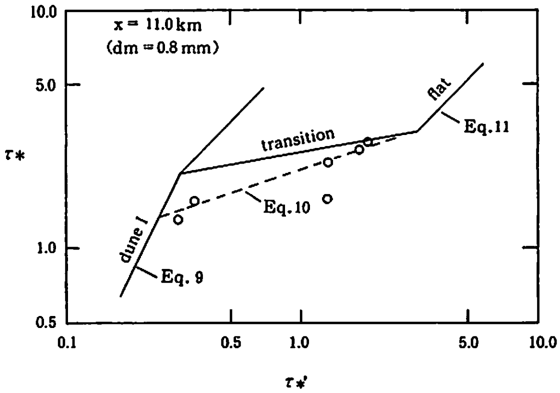


Fig. 9 Relationship between τ_* and τ_*'

$$\tau_*' = \frac{R'I_e}{sd_m} \tag{7}$$

$$\frac{U}{\sqrt{gR'I_e}} = 6.0 + 5.75 \log \frac{R'}{2d_m} \tag{8}$$

in which U=areal average velocity of flow; and R'=hydraulic radius due to grain shear stress. As shown in Fig. 9, the bed configuration at this reach shifts from "dune I" to "transition" at a smaller τ_* than predicted by the theory (9). It is found that the sand wave on the bed decays and the roughness factor decreases with increasing flow rate and τ_*.

According to Fig. 9, the following relationships between τ_* and τ_*' are adopted in the present analysis of flow in the main channel. On the other hand, Manning's mean velocity formula is applied to the flow on the flood plain with n= 0.04.

$$\tau_*' = 0.21\,\tau_*^{\frac{1}{2}} \quad \text{for} \quad \tau_* < 1.35 \tag{9}$$

$$\tau_*' = 0.10\,\tau_*^3 \quad \text{for} \quad 1.35 \leqq \tau_* < 3.16 \tag{10}$$

$$\tau_*' = \tau_* \quad \text{for} \quad 3.16 \leqq \tau_* \tag{11}$$

Water surface elevation at the downstream end at each time is given by the field observation. Slope of energy gradient I_e is calculated from Eq. 8 with one of the Eqs. 9 to 11. A succesive computation of water surface elevation is performed by Eqs. 12 and 13 in the main channel and the flood plains.

$$\left(\frac{aQ^2}{2gA^2} + H - \frac{\Delta x}{2} I_e\right)_U = \left(\frac{aQ^2}{2gA^2} + H + \frac{\Delta x}{2} I_e\right)_D \tag{12}$$

$$Q = \sum_{j=1}^{N} U_j \cdot A_j \tag{13}$$

in which subscripts U and D signify the values corresponding to upstream and downstream sides of a finite distance Δx. $N=3$, and j signifies the value of j-th section in a cross section of the river channel. Some approximate relationships expressed by power laws were used instead of Eq. 8 in the computer program for a convenience. For more details of the computation, Shimizu and Itakura (12) could be referenced.

RESULTS AND DISCUSSION

One-dimensional calculation of the bed variation is performed for the reach of the Ishikari river from the river mouth to 8*km* up-stream. A profile of cross sectionally averaged bed surface observed in May 1981 is given as the initial condition and an unsteady flow rate shown in Fig. 5 is applied. At the river mouth, the water surface elevation which was obtained by the field observation is given as the boundary condition at the downstream end. Computations of sediment transport and bed variation are performed only in the main channel, in which $\Delta x = 500$ *m* and $\Delta t = 10$ sec to 1 hr. Size of the bed material in this reach varies with distance as shown in Fig. 10 and a straight line in Fig. 10 is applied in the calculation. Distribution of size of the bed material at each distance is assumed by an interpolation of two distributions at downstream and upstream ends shown in Fig. 11.

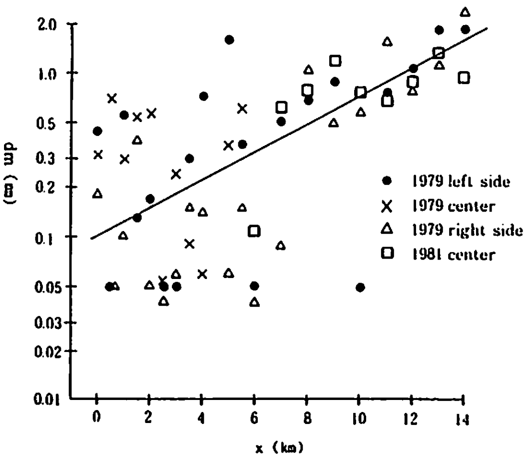


Fig. 10 Mean diameter of bed material

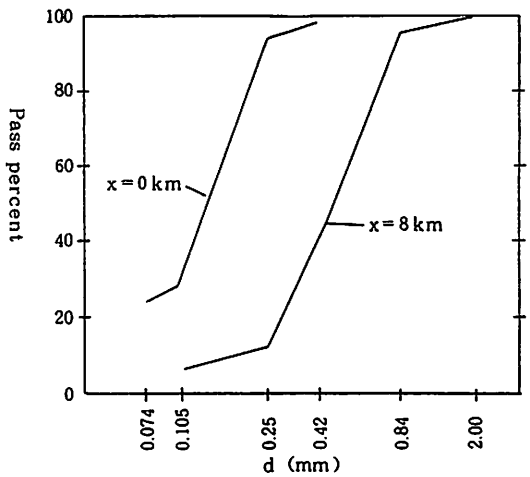


Fig. 11 Distribution of size of bed material

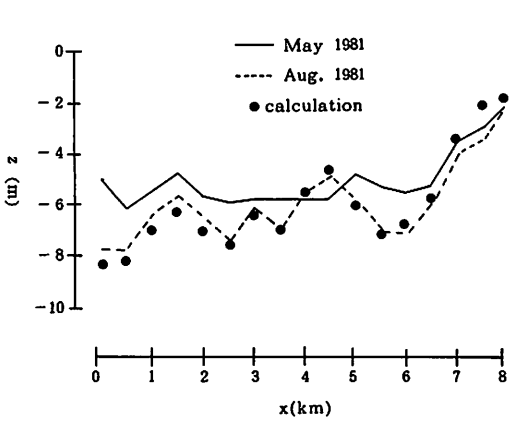


Fig. 12 Longitudinal profile of average bed surface

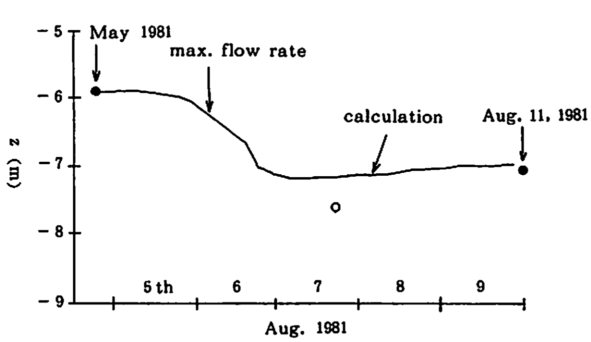


Fig. 13 Variation of average bed surface with time

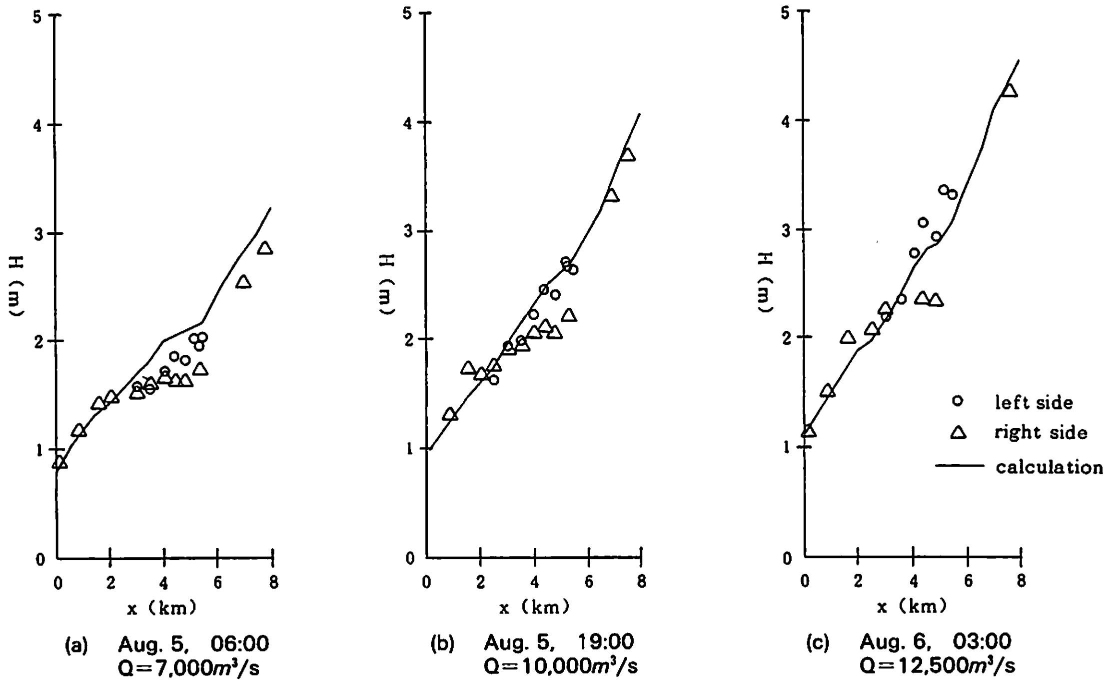


Fig. 14 Water surface profiles

Calculated longitudinal profile of the bed surface after the 1981-flood is plotted in Fig. 12 compared with the observations. Fig. 13 shows an example of the bed variation with time at a station 3.5*km* upstream from the river mouth. In Fig. 13 a plot is included which was estimated from the measurement of the longitudinal bed profile during the flood. When Fig. 13 is compared with the hydrograph shown in Fig. 5, it is found that a rapid degradation of the bed is observed at the flow rate Q>7,000 m^3/sec and $\tau_*' > 1.0$ and sand particles deposit very slowly after the flood.

Calculations of the profiles of the water surface elevation are shown in Figs. 14 (a), (b) and (c) for several flow rates compared with field observations and good agreements can be observed.

It is concluded that the proposed simulation model for calculating the bed variation in river channel was confirmed by the field observations.

CONCLUDING REMARKS

A detailed observation of a flood was performed in the Ishikari River in August 1981. It was found that the channel geometrical characteristics and hence the hydraulic roughness depend on the depth, velocity and sediment transport rate of the flow, but these flow properties were in turn strongly dependent on the channel configuration and its hydraulic roughness. A one-dimensional numerical simulation model to calculate the bed variation was proposed taking into account the variation of the hydraulic roughness and the transport rate of suspended sediment. The calculations well agreed with the field observations and a validity of the simulation model was confirmed.

The proposed simulation model to calculate the bed variation will be a useful tool to estiamte the characteristics of the channel geometry during a flood and to design a river channel in establishing a river improvement plan. A two-dimensional model to predict the bed variation has been developed and will be published later.

This paper is basically an English translation of a paper presented to the 30th Japanese Conference on Hydraulics, JSCE in February 1986 by the authors (11).

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APPENDIX–NOTATIONS

The following symbols are used in this paper:

A =cross sectional area of flow;
ΔA =increment of cross sectional area;
B =width of channel;
C =dimensionless volumetric concentration of suspended sediment;
C_b =reference concentration;

$\bar{C}$	=areal average of C;
d	=particle size of sediment;
d_m	=mean diameter of sediments;
f	=function of U_{*ci}^2/U_*^2 in Eq. 5;
g	=acceleration due to gravity;
H	=elevation of water surface;
h	=depth of flow;
I_e	=slope of energy gradient;
n	=Manning's roughness coefficient;
P_i	=fraction of sand particle of diameter d_i in a mixture of bed material in exchange layer;
P_{i0}	=fraction of sand particle of diameter d_i in a mixture of bed material below exchange layer;
Q	=flow rate;
q_B	=transport rate of bed load by volume per unit width;
q_{BT}	$=\Sigma q_{Bi}$, total bed load transport rate per unit width;
q_{su}	=rate of detachment of suspended sediment from unit area of bed surface;
R'	=hydraulic radius defined by Eq. 8;
s	=specific weight of sediment in water;
t	=time;
U	=areal average velocity;
U_*	$=\sqrt{ghI_e}$, shear velocity;
U_{*c}	=critical shear velocity;
W	=fall velocity of sediment;
x	=coordinate in direction of flow;
y	=coordinate perpendicular to x and z;
z	=elevation of bed surface;
α	=coorection factor for velocity head;
β	=parameter in Eq. 4;
δ	=thickness of exchange layer of bed;
ε	=diffusion coefficient;
κ	=0.4, von Karman constant;
λ	=porosity of sediment;
τ_*	$=hI_e/sd$, dimensionless shear stress;
τ_*'	$=R'I_e/sd$, grain shear stress; and
ϕ	=4, parameter in Eq. 5.

Subscripts:

i	signifies the value corresponding to fraction i of a non-uniform mixture of sediment represented by a specific diameter d_i of bed material.
m	signifies the value referred to the mean diameter of bed material.