CHANNEL MORPHOLOGY OF MOUNTAIN STREAMS AND INHABITATION OF MASU SALMON

Kazuyoshi Hasegawa[1]

[1] Fellow Member of JSCE, Dr. of Eng., Research Adviser of Foundation of River & Watershed Environment Management (S1 W7 Sapporo 060, Hokkaido, Japan)

Morphological channel forms observed in many mountain streams show superposition of small-, medium- and large-scale bedforms. The small-scale bedforms are identified as step pool bedform of which origin should be antidune formation and sorting of bed materials. Medium-scale bedforms is corresponding to alternating bars composed of boulders and cobbles. Both bedforms coexist and are superposed. Prediction equations for the wavelength and height of a step pool can be derived from the theory of antidune. The first trial to construct a new type fish-way using the theoretical spacing for step pools was conducted in the site of Takizawa Dam. Field survey on inhabitation of masu salmon (cherry salmon) in a step pool stream was performed and it was found that the step pool system which provides both areas with high and low Froude numbers is a suitable habitat for salmon fishes.

Key Words : *Mountain stream, small-scale, medium-scale, large-scale, bed-form, step pool, alternating bar, Froude number, fish-way, inhabitation, masu salmon*

1. INTRODUCTION

Research on mountain streams has been sharply increasing over the past 10 – 15 years. There would be social requests for rehabilitation or restoration etc. of streams as the back ground. Chin[1] publishes the detailed reviews about them.

Author has concerned in the various problems of mountain streams since some 25 years ago. In this article, interesting and important topics which seem not to be so old compared with the recent researches will be presented from the results obtained by the authors.

2. SCALE CLASSIFICATION OF BED FORMS IN MOUNTAIN STREAMS

(1) Features of longitudinal bed profile

Fig.1 shows a part of surveyed result of longitudinal bed profile for the Ogawa River located in the outskirts of Sapporo. The river is a typical mountain stream of which drainage area is 10.8 km^2, length is 7.0 km and mean gradient is 0.102. Horizontal axis in Fig.1 is distance measured along center line of the channel toward upstream from the confluence. Vertical axis means specific bed height measured from the mean slope of channel. Complex undulation in the figure corresponds to bed configuration, which seems to be composed of three factors with different wavelength as follows:

(a) Small-scale bed forms with short wavelengths as seen saw-blades in the figure (mean wave length 4.2m).

(b) Medium-scale bed forms with about 30m mean wavelength which composed of several small scale bed forms.

(c) Large-scale bed forms with 100m to 200m or moreover wavelength.

Such superposition of small, medium and large scale bed forms is widely recognizable in many gravel bed streams to be an important characteristic of the streams.

(2) Small-scale bed forms

These bed forms are usually called as step pools. However, it has been known that there are plural different kind of forms in them. If limited to gravel bed streams, formation of step pools can be caused by actions of antidune formation and gravel sorting under the supercritical flow condition as Whittaker and Jaeggi[2] pointed out. This was reconfirmed by Ashida *et als*.[3] and continuously by the author *et als.*[4][5][6]. The author *et al.*[4] found furthermore, that there are two kind of step pool systems in gravel bed streams. One is transverse ribs as shown in Fig.2 (the Gunbetsu Riv.) for a typical example, in which the materials constituting a step are aligned in a straight line transverse to flow direction and the pool is scoured relatively shallow. The other is round step pools as shown in Fig.3 (the Bankeisawa Riv.), in which the materials to form a step are placed in an arch horizontally and waterfalls or cascades with a small plunge pool are created. The latter is considered to be formed by synchronization of the wavelength of a forced surface wave caused by antidune on the bed and the wavelength of a stationary surface diagonal wave in the chute flow[4].

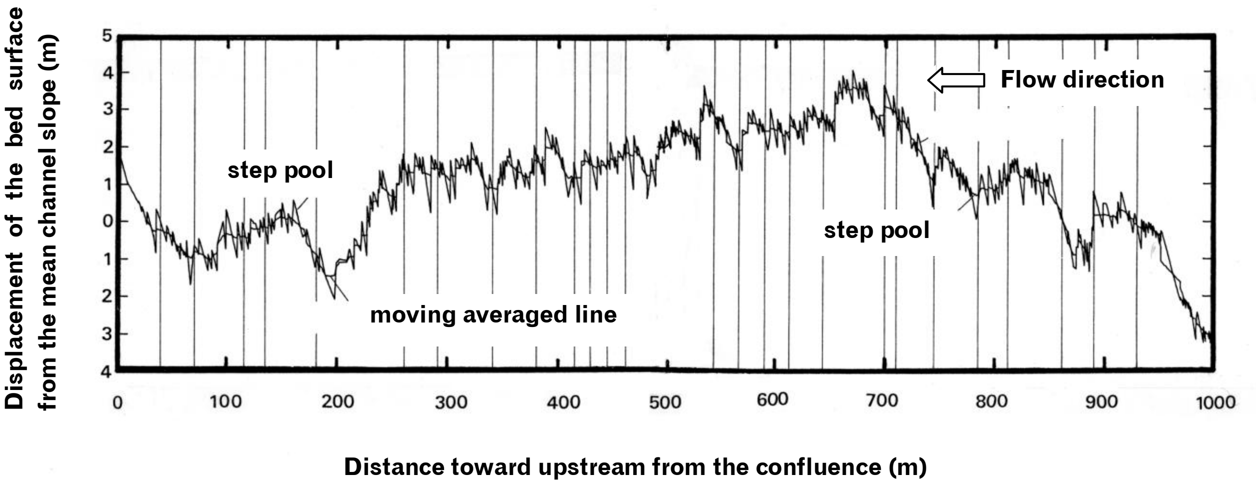

Fig.1 Longitudinal bed profile along the center line of channel in a partial section of the Ogawa River measured from the mean bed slope. Vertical bars nearly correspond to the locations of apices of channel meandering bends.

Fig.2 Transverse ribs in the Gunbetsu River (Left)

Fig.3 Round step pools in the Bankeisawa River (Right)

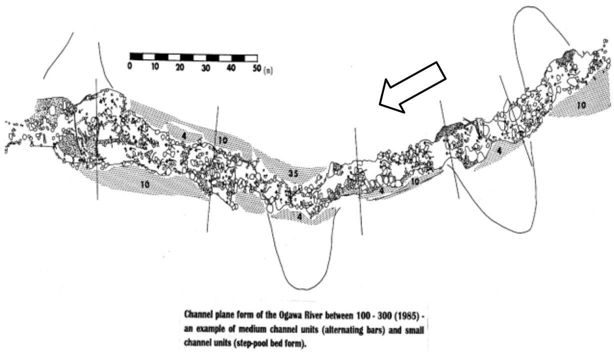

Fig.4 A part of plan form of the Ogawa River from 100m to 300m in Fig.1. Shadowed areas and curved lines mean accumulating bars and erosions of the valley wall, respectively. Transverse lines show the locations for large steps to lie.

(3) Medium-scale bed forms

The medium-scale bed form in Fig.1 has wavelength of 3 - 4.5 times of the channel width and shows triangular shape with a long gentle back slope and a steep front slope (large step). The form can be identified to alternating bar which is prevalently observed in the alluvial plane reach. Fig.4 is a plan form of a partial area of the Ogawa River corresponding to the section from 100m to 300m in Fig.1. Shadowed areas and curved lines mean accumulating bars and erosions of the valley wall, respectively. Transverse lines correspond to the locations for large steps to lie. It is obvious that the main stream meanders alternately every medium-scale bed forms to erode the valley wall. Step pools develop and coexist on the medium-scale bed forms. Fig.5 indicates the schematic diagram of the coexistence of medium- and small-scale bed forms, which is corrected from Grant *et als.*[7].

(4) Large-scale bed forms

Further large scale undulation which has 200 – 300m wavelength is recognizable in Fig.1. This type of undulation correlates with the change of valley width and the extension of channel braids[8].

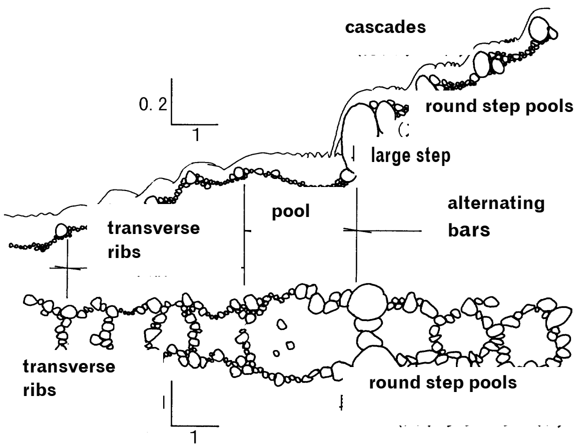

Fig.5 Schematic diagram of the coexistence of medium- and small-scale bed forms. Corrected from Grant *et als.*[7]

3. APPLICATION OF STEP POOL SYSTEMS TO FISH-WAY

(1) Geographical characteristics of step pools

Reflecting the origin of transverse ribs, their wavelength well agrees with the theoretical one of antidune. If the Hayashi[9] equation is used for critical condition of antidune formation, it is written as follows.

$$F_r^{\,2} = \frac{1}{kh\tanh(kh)} \qquad (1)$$

Here, k = wave number of antidune $= 2\pi/\lambda$, λ = wavelength, F_r = Froude number of mean flow, h = mean water depth.

By adopting the first and second terms of Taylor expansion for the right hand side above equation, the following simple relation can be derived.

$$= 2\pi\lambda\sqrt{F_r^{\,2}\ h\ \frac{1}{3}} \qquad (2)$$

On the other hand, wave height Δ of a step pool can be expressed by the next equation in view of many field measurements and experiments.

$$\Delta = D_{84} \qquad (3)$$

Where, D_{84} is the 84th percentile particle size.

As Ashida *et als.*[3] pointed out, the gravels or cobbles forming a step are under the condition of critical shear stress. Then, Δ can be described by using the critical Shields shear stress τ^*_{c0}, as

$$\Delta = D_{84} = \frac{hI}{s\tau^*_{c0}} \qquad (4).$$

Here, I is mean bed slope, s is submerged specific gravity of the grain.

Furthermore, it is known that Hey equation well represent mean velocity of flow on step pools bed. The approximated equation on it is written by the following power function.

$$\frac{u}{u_*} = 6.5\left(\frac{h}{3.5D_{84}}\right)^{1/4} \qquad (5)$$

Therefore, mean water depth h can be derived to use $u = Q/(Bh)$ as follows. Where, u is men flow velocity, u_* is shear velocity and Q is discharge of the flow.

$$h = \left(\frac{3.5^{1/4} D_{84}^{\ 1/4} Q}{6.5B\sqrt{gI}}\right)^{4/7} \qquad (6)$$

From Eqs. (4) and (6), final form for the wave height can be obtained as

$$\Delta = 6.43 I^{\frac{5}{6}} h_c \qquad (7)$$

$$h_c = \left(\frac{Q^2}{gB^2}\right)^{1/3} \qquad (8).$$

Here, $\tau^*_{c0} = 0.05$ and $s = 1.65$ are used.

If substitute the Froude number derived from Eq.(5) and also Eq.(6) into the Eq.(2), the final form for wavelength becomes

$$\lambda = 3.36\sqrt{6.48\sqrt{I} - \frac{1}{3}}\, I^{-\frac{1}{6}} h_c \qquad (9).$$

These equations comparably well agree with the experimental data. Fig. 6 shows the comparison between Eq.(7) or Eq.(9) and histograms of wave height or wavelength observed in many experiments under various hydraulic conditions[6]. The theoretical curves seem to pass near the most frequent values of Δ/h_c or λ/h_c, according to the change of channel slope.

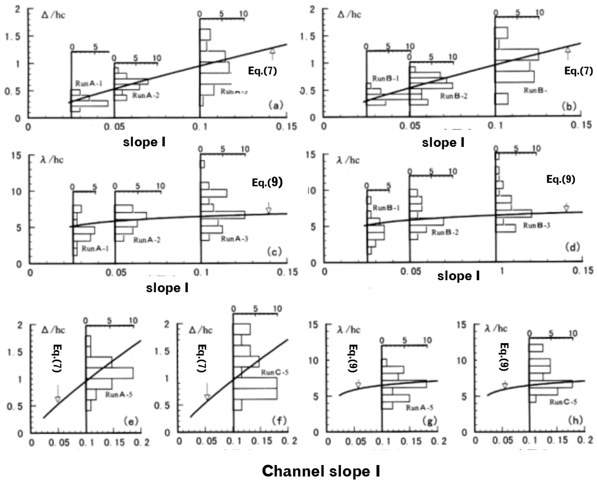

Fig.6 Comparison of the theoretical equations for wave height and wavelength to histograms of them in experimental data.

Fig.7 Objective example of the stream type fish-way. constructed at the site of debris dam for Takizawa Dam (Japan Water Agency). The spacing and height of steps, the channel width, the side wall height and the slope are 3.5m, 0.5m, 3.7m, 0.6m and 1/10, respectively. (Courtesy Dr. H. Tatsuzawa)

(2) Application to fish-way

Tatsuzawa *et als.*[10] proposed and designed a mountain stream type fish-way which is composed of artificial step pools providing the spacing and height evaluated from planed channel slope and unit width discharge through Eq.(7) and Eq.(9). Cobbles forming a step are fixed or stabilized in a slightly arched line on the assumption of a rib at the bottom for the convenience of maintenance. Pool is established by the scouring of natural flow for the primary bed which was laid out with the local bed materials. Fig.7 shows the only objective example of this type of fish-way, which was constructed at the site of debris dam for Takizawa Dam (Japan Water Agency). One of the merits of this type fish-way is even when it was filled with debris or sand, water equivalent to design discharge can reforme the bed height. If the design discharge is equivalent to discharge with a return period of one year or shorter, the fish-way can draw off several times a year the sediments by own running flow.

4. INHABITATION OF MASU SALMON IN STEP POOL STREAMS

Masu salmon *Oncorhynchus masou masou* is salmonidae fish which was remained in upstream region of inland rivers. Field investigation for inhabitation of masu salmon in step-pool streams was conducted in the Gunbetsu River (Fig.8, Fig.9) in Oct., 06, and July, Nov., 07, in order to know the relation between flow characteristics within a step pool section and the inhabiting distribution of masu salmon. It will enhance development in design of fish-way and also in stream restoration. Salmon fishes have a habit while they stay ordinarily in place with a gentle current like pools, dash to the place with a rapid current to catch flowing foods. Therefore, a hypothesis could be considered that a step pool system which provides both areas with high and low Froude number is a suitable habitat for salmon fishes. Fig. 10 shows current velocity, water depth, Froude number and inhabitation density of masu salmon averaged in every pool of the site. Fig. 11 demonstrates a relation between maximum-minimum ratio of local Froude number in each pool and the numbers of masu salmon inhabiting the pool. The hypothesis will be valid.

Fig.8 Investigation site of the Gunbetsu River, Hokkaido

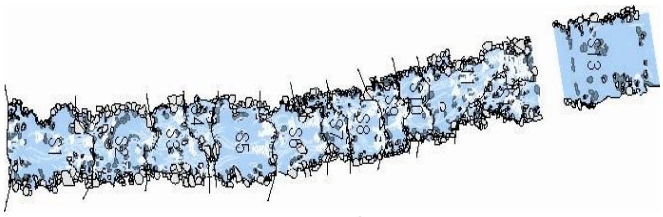

Fig.9 Step pool sections of investigation site in the Gunbetsu River

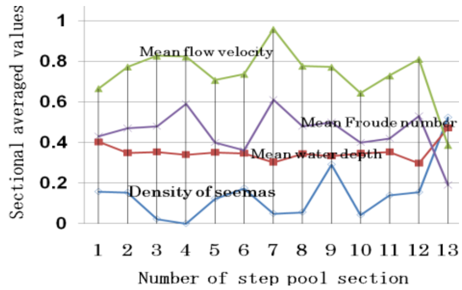

Fig.10 Sectional averaged hydraulic values in each pool.

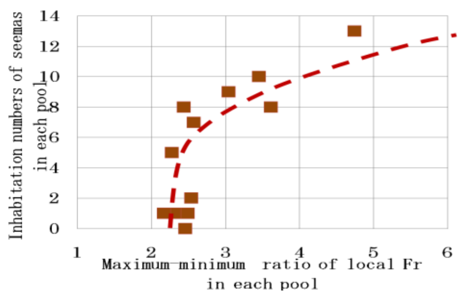

Fig.11 Relation between maximum-minimum ratio of local Froude number in each pool and the number of masu salmon inhabiting the pool.

5. SUMMARY

(1) Morphology in mountain streams consists of small-, medium- and large- scale bedforms.

(2) Small-scale and medium-scale bedforms are identified as step pools and alternating bars, respectively. Both coexist being superposed.

(3) Wavelength and height of a step pool can be estimated from simple functions of channel slope and unit width discharge. These are applied to development of new fish-way.

(4) A step pool system which provides both areas with high and low Froude numbers is a suitable habitat for salmon fishes.

REFERENCES

1) Chin, A. and E. Wohl : Toward a theory for step pools in stream channels, *Progress in Physical Geography* 29,3 pp.275-296, 2005.

2) Whittaker, J. G. and M. N. R. Jaeggi : Origin of step-pool systems in mountain streams, *Jour. of Hydraulics Div., Proc. of ASCE*, pp.758-773, 1982.

3) Ashida, K., S. Egashira and N. Ando : Generation and geometric features of step-pool bed forms, *Kyoto University, Disaster Prevention Research Institute Annuals*, No.27 B-2, pp.341-353, 1984 (in Japanese).

4) Hasegawa, K. and S. Kambayashi : Formation mechanism of step-pool systems in steep rivers and guide lines for the design of construction, *Annual Jour. of Hydraulic Eng.* Vol.40, pp.893-900, 1996 (in Japanese).

5) Tatsuzawa, H., H. Hayashi and K. Hasegawa : Role of heterogeneous property of bed materials in the formation of step-pool systems in mountain streams, *Jour. of Hydroscience and Hydraulic Eng.*, Vol.17, No.1, pp.37-45, 1999.

6) Tatsuzawa, H., H. Hayashi and K. Hasegawa : A study on small-scale bed topography in mountain streams – Application of step and pool systems for design of a new fish-way -, *Jour. of Hydraulic, Coastal and Environmental Eng., JSCE*, No.656/II-52, pp.83-101, 2000 (in Japanese).

7) Grant, G. E., F. J. Swanson and M. G. Wolman : Pattern and origin of stepped-bed morphology in high-gradient streams, Western Cascades, Oregon, *Geological Society of America Bulletin*, V. 102, pp.340-352, 1990.

8) Meguro, H., K. Hasegawa and K. Nakamura : Experimental reproduction of braided channels and bedforms with three different scales observed in mountain rivers, *Jour. of Hydroscience and Hydraulic Eng.*, Vol.20, No.2, pp.141-153, 2002.

9) Hayashi, T.: Formation of dunes and antidunes in open channel, *Jour. of Hydraulic Div. Proc. of ASCE*, Vol.96, No. HY2, pp. 357-366, 1970.

10) Tatsuzawa, H., K. Hasegawa, M. Yokota and A. Higuchi : A study of a new fish-way on dams in mountain streams, *12th Congress on large dams*, Vol. II, pp.945-965, 2000.

(Received January 31, 2009)