Field Study on Bank Erosion due to a Crank Flow in a River Channel which has Divergence Convergence Meandering System

Tomokazu MISHINA* and Nyosen SUGA**

*Chief-Eng. Chuohteck. Co. Ltd, 310-0902, Watari3082, Mito city, Ibaraki, JAPAN

** Prof. Emeritus, Univ. of Utsunomiya, 276-0023, Katsutadai4-2-4, Yachiyo city, Chiba, JAPAN

I. INTRODUCTION

This paper deals with a new concept of bank erosion in a river caused by bank attacking concentrated flow at sharp angle due to crank flow as was introduced in Ref. [1] and [7].

Definition and characteristics of crank flow are shown below. Crank flow is a flow pattern which has plain shape of crank. And after development, crank flow becomes to a bank attacking concentrated flow at sharp angle to the bank, and brings large scale bank erosion. Development process of crank flow is divided into two categories; the one by natural condition and the other by artificial condition.

This paper treats the case of crank flow developed by the deformation of morphological meandering shape divergence convergence channel system. This kind of crank flow occurs frequently according to the increase of artificial actions recently. Divergence-convergence meandering system which was also introduced in Ref. [5] and [6] develops under the condition of bed material sifting during flood flow. And the phenomena are mainly characterized to rivers which have graded large bed materials. In this case, formation of jam-up deposit of large stones promote to make flat and wide channel up-stream, and also steep and narrow channel down stream.

Practically in many rivers in Japan, the developments of various types of crank flow are recently becoming remarkable. As for the damages, the suffering cases of bank erosion caused by crank flow increase quantitatively and some of then are recognized beyond sufferance qualitatively. For example, length of damage of bank erosion exceeds 100m (about one-third of channel wide) laterally in a flood time (one day) occurred in Kinu-river 2001.

In this paper, main causes of development and the classification of crank flow are discussed based on field investigation in such rivers as Kinu and Watarase River. In those rivers, typical strong bank attacking concentrated flows at sharp angle to the bank due to the development of crank flow are appearing, according to the degree of deformation of meandering system mainly by artificial action. In this case, the meandering system in the fan shape land of Kinu and Watarase river is characterized by the divergence convergence meandering channel system.

Thus, the recent remarkable bank erosion caused by crank flow in a river which has divergence-convergence system is elucidated based on field study. Results of this study are expected to contribute to practical application and offer suggestions to farther development of the study. And also as countermeasures, mitigated relieved method and restoration of the channel meandering system are proposed besides the hither to direct protection as revetment method.

II. ACTUAL CONDITION OF CRANK FLOW

A General feature of Crank flow

Three items are mentioned as main characteristics of crank flow as follows. a) plane shape of thal-weg is crank-like. b) bank attacking concentrated flow at sharp angle to the bank. c) crank flow brings large-scale bank erosion. Typical example of crank flow is shown in Photo. 1. And also, Ref. [1] and [7] shows that characteristics of crank flow and introduction of several types of crank flow.

Development process of crank flow is divided into two classified categories based on the natural condition and artificial condition. As natural conditions, meandering river at mountain alluvial land is mentioned as an example. In this case, the importance of existence of many large stones is indicated as that the channel meandering is easily occurred where jam-up deposit of large stones and the local scour around it develop, or in the case of gravel bed without large stones, crank flow is formed as straight flow from edge to edge of rock bank in the width of forced meandering alluvial land. Above-mentioned results were

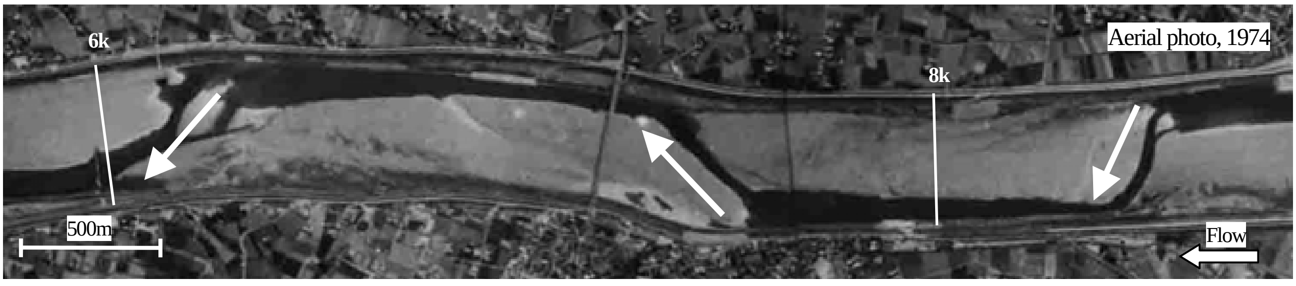

Photo 1. A typical example of crank flow (Down stream alluvial reaches of Naka river)

obtained by the field investigation of natural meandering pattern at mountain alluvial land in Yosasa-river, as stated in Ref. [2] and [3].

As artificial conditions for the development process of crank flow deformation of the meandering features the construction by channel works in the divergence-convergence meandering river is mentioned. The river bed degradation is an alternate bar channel is also one of the important additional causes as shown in photo. 1.

In this paper, the cases of divergence-convergence channels where the development of crank flows are remarkable are investigated. The objected rivers are Kinu-river and Watarase-river, tributaries of the Tone River. Basic structure of divergence convergence channel system is described later. Concerning the power of crank flow for bank erosion, relationship between discharge/water depth and velocity was shown in Fig.1.

Velocity increased near the bank occurs even during small flood when the water level is below the surface of sand bars, under the condition of development of deformation of meandering system. Those phenomena occur, corresponding to middle scale flood and also decreasing term of discharge in big flood , in accordance with the development of bed degradation of the thal-weg. But, the velocity near the bank is moderate, and the maximum velocity during large scale flood appears at the center of the channel laterally, before the deformation of meandering system occurs, maintaining the original two lane meandering channel pattern. As stated in Ref. [4], two lane meandering system is stable under the natural condition, and even big flood flows do not exert influence on river bank due to the moderate velocity near the bank.

But recently, meandering pattern is gradually deforming. Among various way of deformation, primary item is the development of flow velocity near the bank and the extension of thal-weg to the down system side along and in front of the newly constructed straight works. This brings the development of extension of distinct straight channel along and in front of the bank which is protected by rigid revetment. Though there are many causes for the change of channel pattern such as dredging, decrease of sediment run off, change of bed material, change of flood scale and flood duration, or vegitation, construction of straight revetment, among them, is considered to be the direct cause by artificial action. Concerning extension of the straight thal-weg, the meandering shape deforms, abrupt change of flow direction occurs in the thal-weg to the other side of the bank across the river, and the bank attacking concentrated flow at

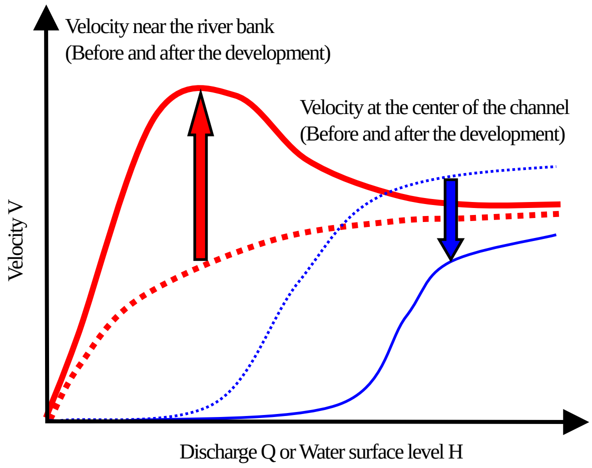

Figure 1. Change of velocity pattern
(Before and after the development of deformation of meandering system)

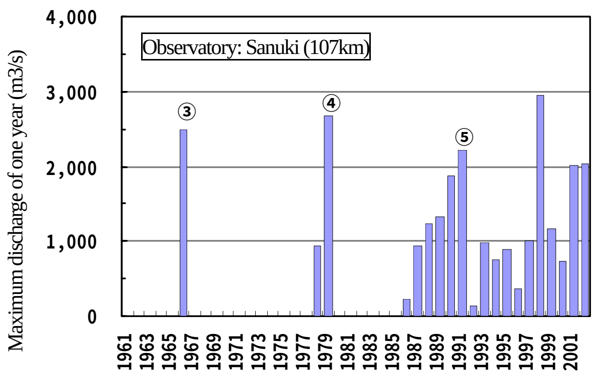

Figure 3. The rate of maximum discharge in Kinu-river
(No data shows non-observation value.)

sharp angle to the bank develops.

B Relation between the Revetment and Crank flow

Fig. 2 shows relationship between extension of revetment and existent of crank flow in Kinu-river. The number of existent crank flow is in increasing tendency. 14 crank flows existed as maximum in 2002. After the war, large-scale disaster restoration works were enforced 5 times as, 1) 1950. 2) 1958-1960. 3) 1966-1967. 4) 1977-1982. 5) 1990-1995. And the maximum rate of flood discharge in those case are shown in Fig. 3. Result of decipherment, shows the increasing of the existence of crank flow after restoration works, and number of crank flows

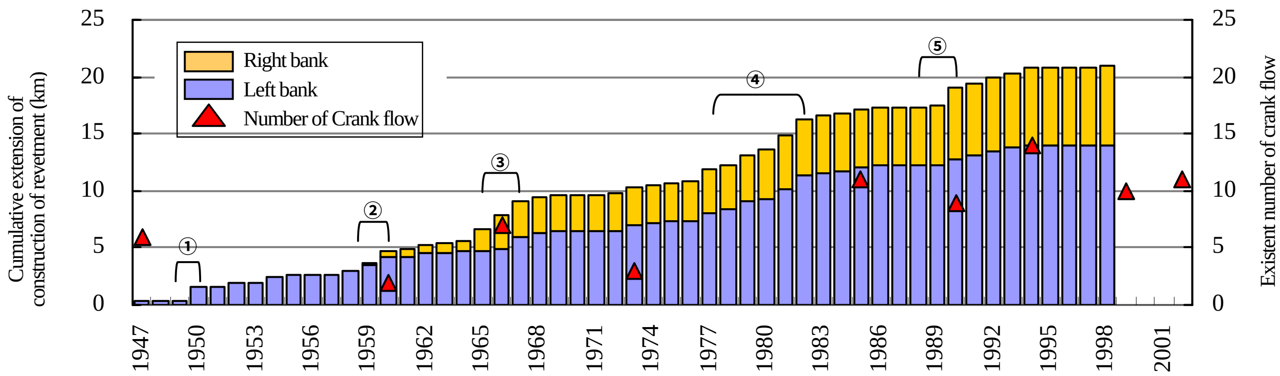

Figure 2. Cumulative extension of revetment works of
and Existent number of crank flow in Kinu-river
(Section: 83-101.5k (L=18.5k), Existent number of crank flow is judged from Aerial photo.)

gradually decreases afterwards in each case. Furthermore number of existent crank flow increases again after the large-scale disaster restoration works.

C Suffering case by Crank flow

Examples the suffering cases in Kinu-river due to crank flow are picked up. The location belong to the reach where bed slope abruptly changes from 1/500 to 1/1,500, longituanaly. The size of bed material also changes from stones to the sand and gravel. Since the channel stability is not enough in this reach, lateral fluctuation of the thal-weg is remarkable compared to the upstream reaches. Photo.2 shows the development of the crank flow between 1994 and 2002, and two pictures of bank erosion of 30m lalerally, 250 m longitudinally, caused by bank attacking concentrated flow during a small flood in 2003. Photograph lot and direction are shown in the serial photograph below right.

In this case, main cause of development of crank flow is considered to be the influence of construction of straight revetment at the left bank. Flow angle at the right bank changed a little and bank materials are also loose composed of sands, gravels and stones. Disaster outbreak first by destruction of existed old revetment, and then erosion of loose bank. The wreckage of old revetment is seen in the picture above left.

D Velocity of Crank flow

Concerning velocity of crank flow at bank attacking concentrated flow does not comprehend sufficiently which some case rivers of really existence of crank flow. Therefore,

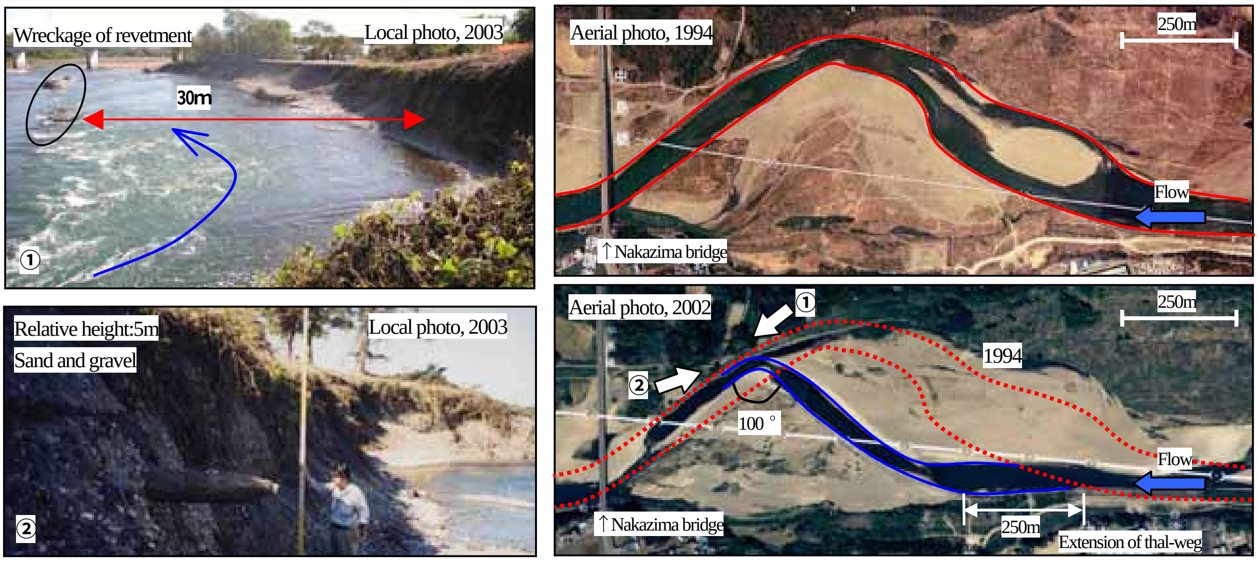

Photo 2. Development of crank flow between 1994 and 2002, and river bank erosion after suffering (2003) in Kinu-river

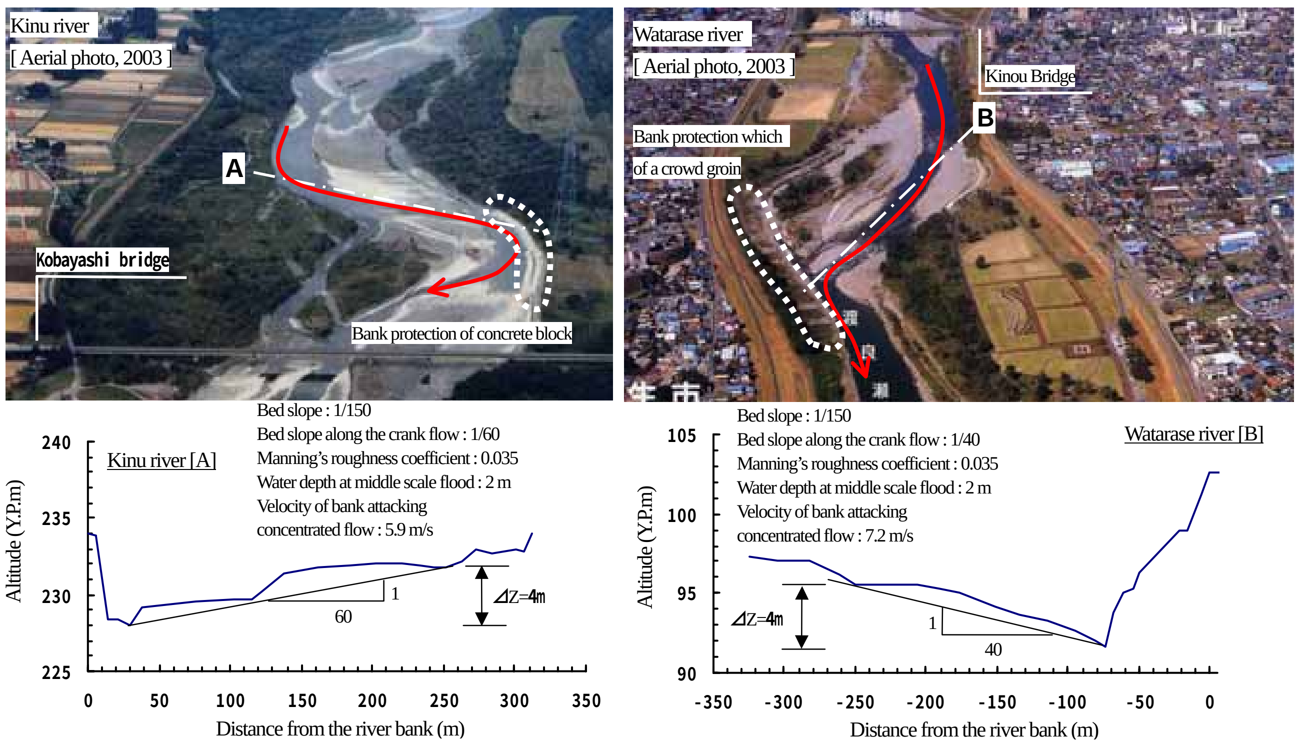

Figure 4. River bed topography along the crank flow [Cases of the Kinu-river and Watarase-river]

field investigation of crank flow is enforced in Kinu-river and Watarase river. Fig. 4 shows the topography of the crank flow in Kinu-river and Watarase-river.

The channels of crank flow in Kinu-river was investigated by field measurement. The results show that the difference of elevation of the bed of the thal-weg at right and left bank is 4m, bed slope of crank flow channel is 1/60, speed of bank erosion between 1999 and 2002 is approximately 17m/year. After disaster suffering caused by the bank attacking concentrated flow due to this crank flow, concrete block revetment is recognized to be constructed as shown in Flg. 4.

On the other hand, many parks and playgrounds were constructed alternatively in the channel of Watarase-river. Though, the original channel of Watarase had also divergence –convergence meandering system, sub lanes of two lane meandering channel were buried to make new land including central bar area, and the two-lane meandering system thus changed into alternate bar meandering system in order to use the land in the channel artificially. And the thal-weg in the alternate bar system has gradually developed to become stable crank flow system. The locations of bank attacking concentrated flow in stable and were found to coincide with the historical location of lateral deposition of jam-up large stones.

Results of topographical field measurement about the crank flow in Watarase-river show that the bed elevation difference of the channel of bank attacking concentrated flow at the positions of left and right bank is 4m, and the slope is 1/40. Large-scale groins is now constructed along the bank as direct protection countermeasure.

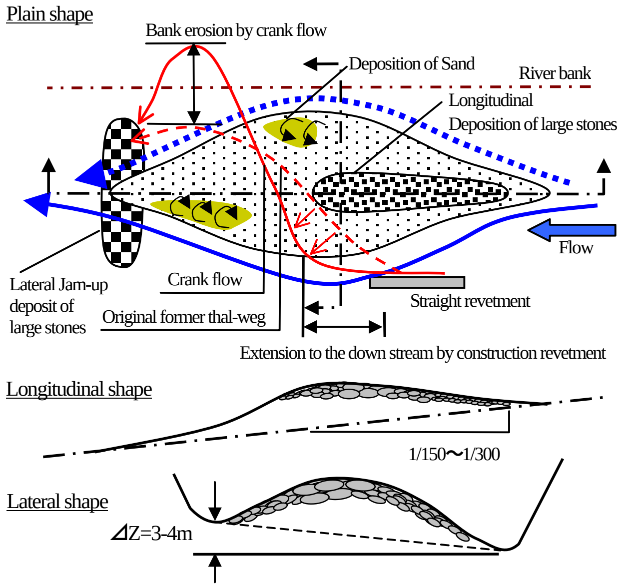

Figure 6. A schematic figure basic structure based on jam-up deposit of large stones and development of crank flow

In this connection, velocity was assumed by calculation as its maximum, based on such assumptions as uniform flow, Manning's formula and water depth 2m, which corresponds to the height of crank flow channel below the top of the surrounding sand bars. According to trial simple 2D calculation in Ref. [9] and [10], this water depth is considered to be suitable

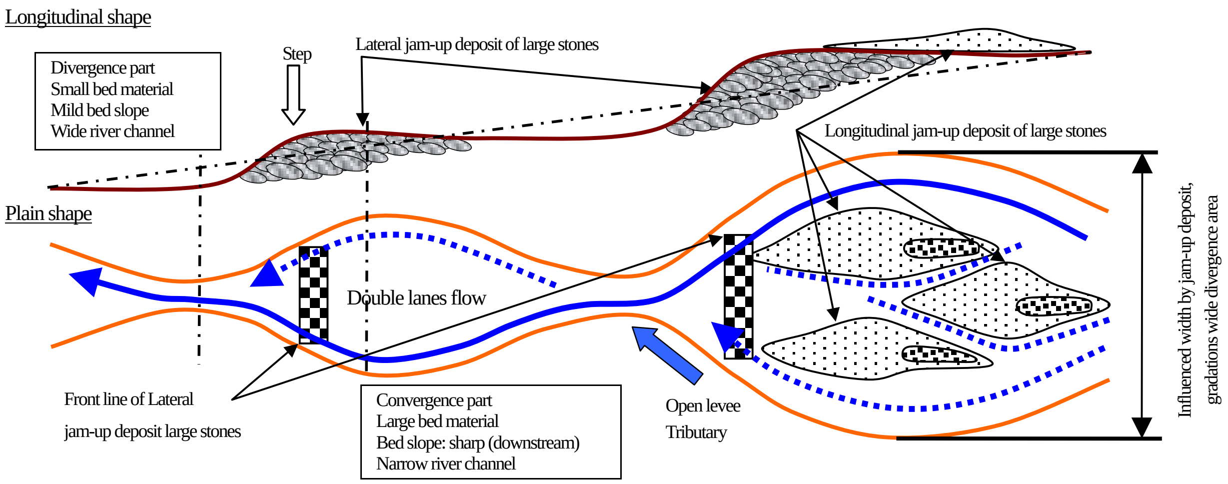

Figure 5. A schematic figure of jam-up deposit large stones and divergence convergence channel

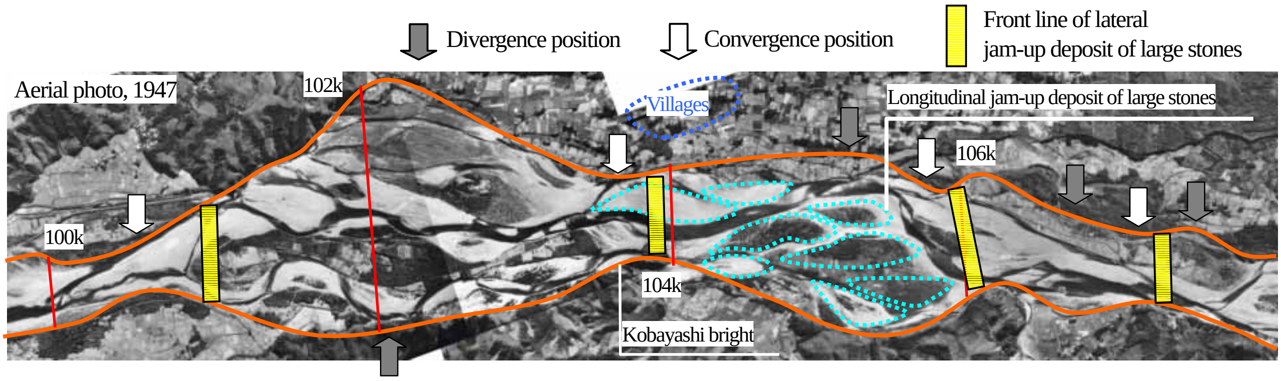

Photo 3. Divergence Convergence channel in Kinu river [Aerial photo, 1947 before construction of levee]

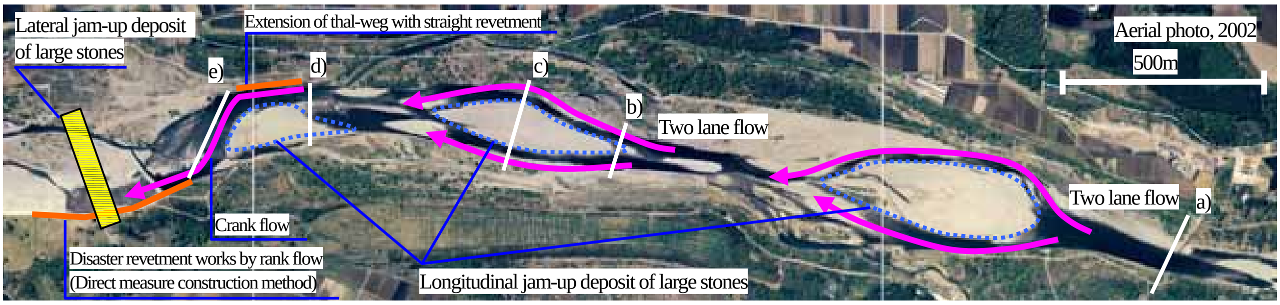

Photo. 4 Two lane meandering channel with the development of longitudinal jam-up deposit of large stones

to the condition that the strength of the crank flow becomes to its maximum during a flood. Calculated results of velocity are 6m/s in the bank attacking concentrated flow at sharp angle at Kinu River, and 7m/s in that of Watarase-river respectively.

III. Divergence Convergence Meandering System

Among various meandering patterns, typical divergence convergence meandering system in Kinu-river and Watarase-river was selected for field investigation. The basic structure of divergence-convergence meandering system based on stable condition of jam-up deposit of large stones, is discussed in Ref. [5] and [6].

Morphological concept of river channel structure has been formed based on bed material sifting during flush flood flows. Those phenomena are mainly characterized to a river which has graded large bed materials. Fig. 5 shows schematic figure of divergence convergence meandering system. Formation of jam-up deposit of large stones causes flat and wide surface up-stream divergence reach, and also steep and narrow convergence reach down stream. Photo. 3 shows that plane shape of divergence convergence channel is watched as in example of aerial photograph at Kinu-river in 1947.

Especially, at the downstream side of jam-up deposit of large stones, open levee and confluence of small tributary are usually exist, and is judged to be the stable deposition.

In this paper, the positions of highly stable lateral jam-up deposit as shown in Fig. 5, are defined according to such items as longitudinal size of bed material, change of bed slope, change of channel width, existence of open levee and confluence of small tributary, existence of step in the protected land, and also direct investigation of bed material by dredging around the proposed position. Fluctuations of the shift and change of thal-weg were investigated too in Ref. [6].

Position of flow channel at divergence area locates to the center of the channel where supercritical flow occasionally occurs at near the peak of big flood, when the big stones are transported and deposited just down stream of the step longitudinally. This deposit forms longitudinal jam up deposit, makes the lateral bed profile convex and becomes the main causes to stabilize the two lane meandering system at convergence reach, as is shown Fig. 6.

Photo. 4 shows that typical two lane meandering channel in

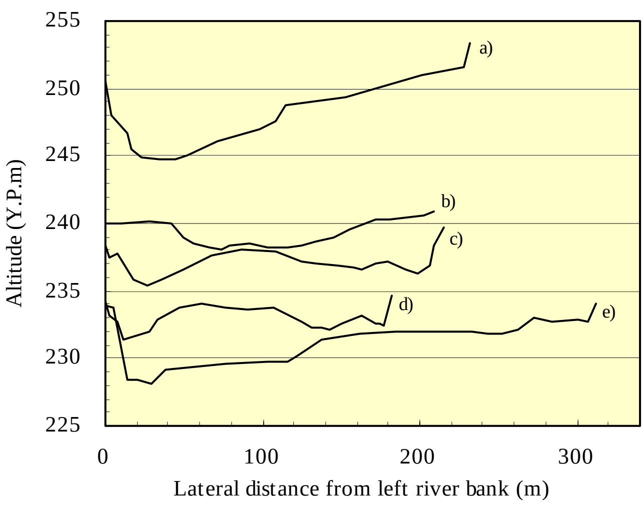

Figure 7. Lateral shape at divergence reach in Kinu river

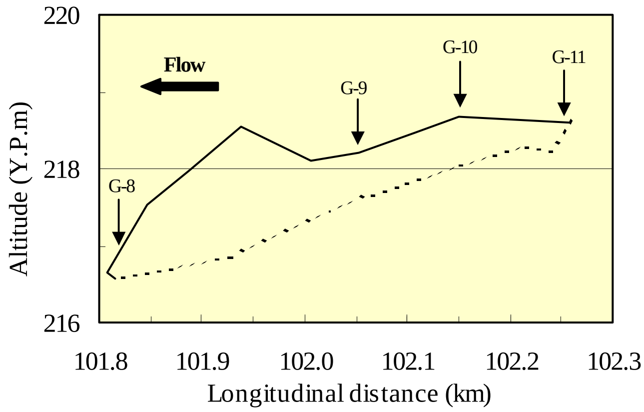

Figure 8. Longitudinal shape of longitudinal jam-up deposit of large stones

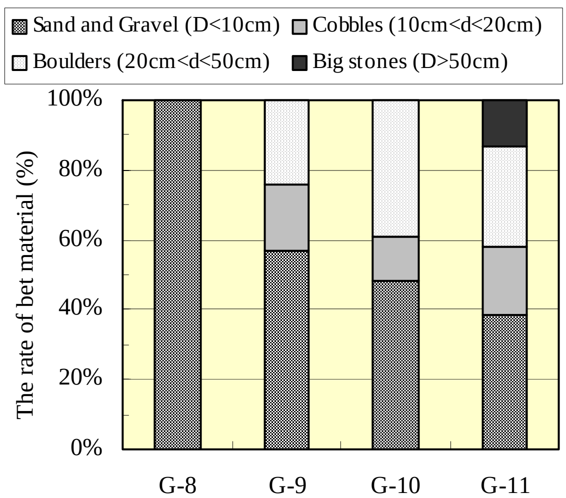

Figure 9. The rate of bed material on the surface of river-bed material rate of longitudinal jam-up deposit of large stones

Kinu-river, and lateral shape in this area shows Fig. 7 at some case of divergence reach. Fig. 8. and Fig. 9. shows that longitudinal shape and bed material at longitudinal jam-up deposit of large stones. Bed material rate appears on the surface river bed by field investigation.

In this area, longitudinal jam-up deposits clearly at the divergence reach, and thal-weg of two lane develops along the right and left bank in channel. In this case, divergence reach with flat and wide is formed by stabled lateral jam-up deposit of large stones. Basic lateral shape of longitudinal jam-up deposit of large stones becomes convex shape, and size of bed material differenced each position as longitudinally. Large-size bed material (cobbles, boulders, big stones) deposit at upper reach, and Small-size bed material (sand or gravel) deposit at down stream, as relatively.

Concerning of formation of longitudinal jam-up deposit of large stones promote to make convex shape laterally at the divergence reach. Point a) exist down stream reach of lateral jam-up deposit of large stones, as a lateral shape is concave. Formation of concave shape is stabled which basic of lateral jam-up deposit of large stones stability. The flow pattern gradually changes from mono lane flow to double lane flow is shown point b) and c). Especially, point c) is formed convex clearly with condition below, degradation of thal-weg at near the both bank developed, and stability of longitudinal jam-up deposit of large stones is high. Also point d) is convex same as point c), presently flowing at the right bank is flowed higher than flowing left bank. Crank flow at this point e) is caused by flow condition of point d), it is described below. Main cause of development of crank flow at the point e) is considered to be the influence of straight revetment at the right bank. In this case, extension of thal-weg to the down stream side is become by straight revetment. Relative height of the thal-weg between right and left banks is 2m at point d) of Fig. 6. Relative height of river bed in crank flow is 4m at point e) of Fig. 7. Damage of bank erosion by crank flow of point e), left bank was eroded 17m in 2001.

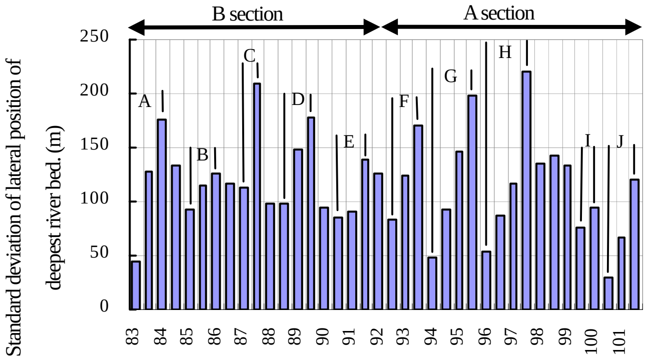

Figure 11. Standard deviation of lateral position of deepest river bed at 83k-101.5k in Kinu-river

This numerical value is the standard deviation of distance to the maximum river bed from the left bank annually. The measurements were done 13 times during 1963-2001.

IV. Development Proces Of Crank Flow

The crank flow treated here develops at divergence reach in the divergence-convergence channel. This area is rather flat and wide, and the stability of the channels on it depends mainly on the scale, number, and their stability of longitudinal jam-up deposits of large stones. Artificial actions such as construction of straight revetment, are another causes to decrease stability as stated in Ref. [7].

Basic structure of divergence area is constituted with several longitudinal jam-up deposits of large stones. And lateral shape is convex. Fig. 6 shows the outline of the structure of deposition of sifted materials, lateral and longitudinal shape, and low water thal-weg in the divergence reach. The occurrence point of crank flow is near the peak of longitudinal bed shape at center. It is illustrated in this case that the construction of straight revetment causes extension of thal-weg along river bank. This extension promotes development of crank flow and also bank attacking

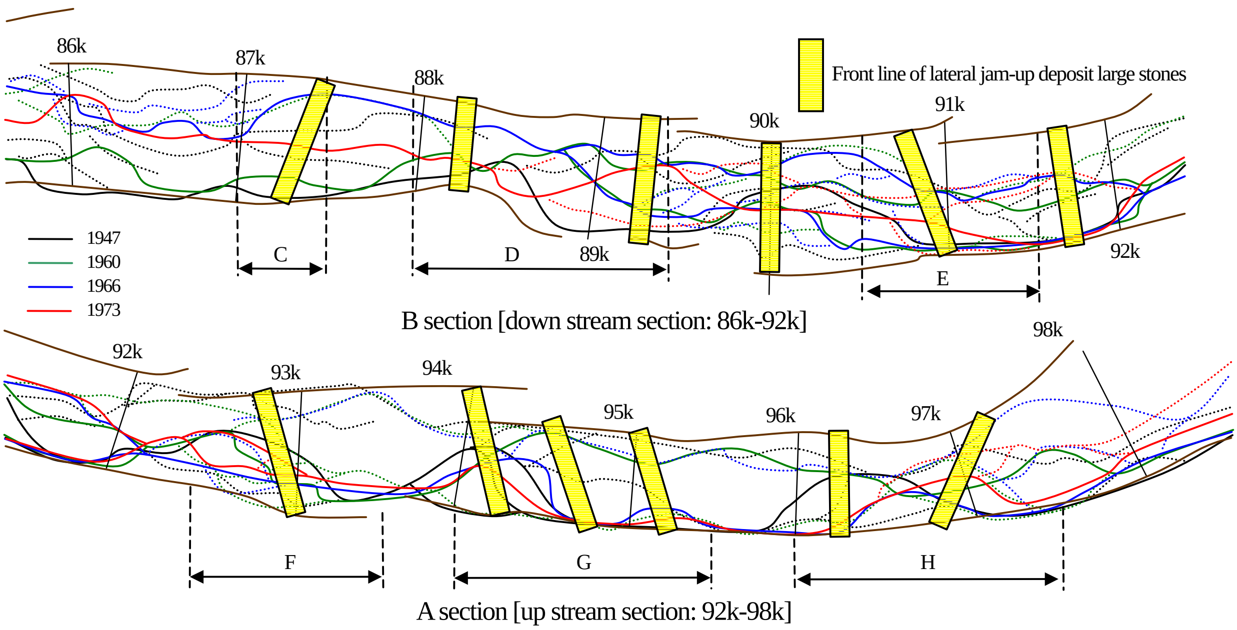

Figure 10. Change of thal-weg at up stream section and down stream section in Kinu-river.

(C-H in the figure shows decrease section to minimum value from the maximum value) concentrated flow at sharp angle at the other side bank.

There is some difference in stability of thal-weg fluctuation between upstream section and down stream section of Kinu-river. Fig. 10. shows that change of thal-weg up stream section and down stream section in Kinu-river.

The up stream section (A section : 92k-98k) has been formed on the original fan shape land and the stable lateral jam-up deposits of large stones are clarified to be stable. On the other hand, down stream section (B section: 86k-92k) was considered to be created about 7,000 years ago by channel shift and has been developing by eroding ash accumulated lager mainly laterally. Lateral jam-up deposits also developed at some interval longitudinally. According to the field investigation, most of them have enough stability but some are found to move 100~200m down stream due to the large scale dredging of the bed after the War.

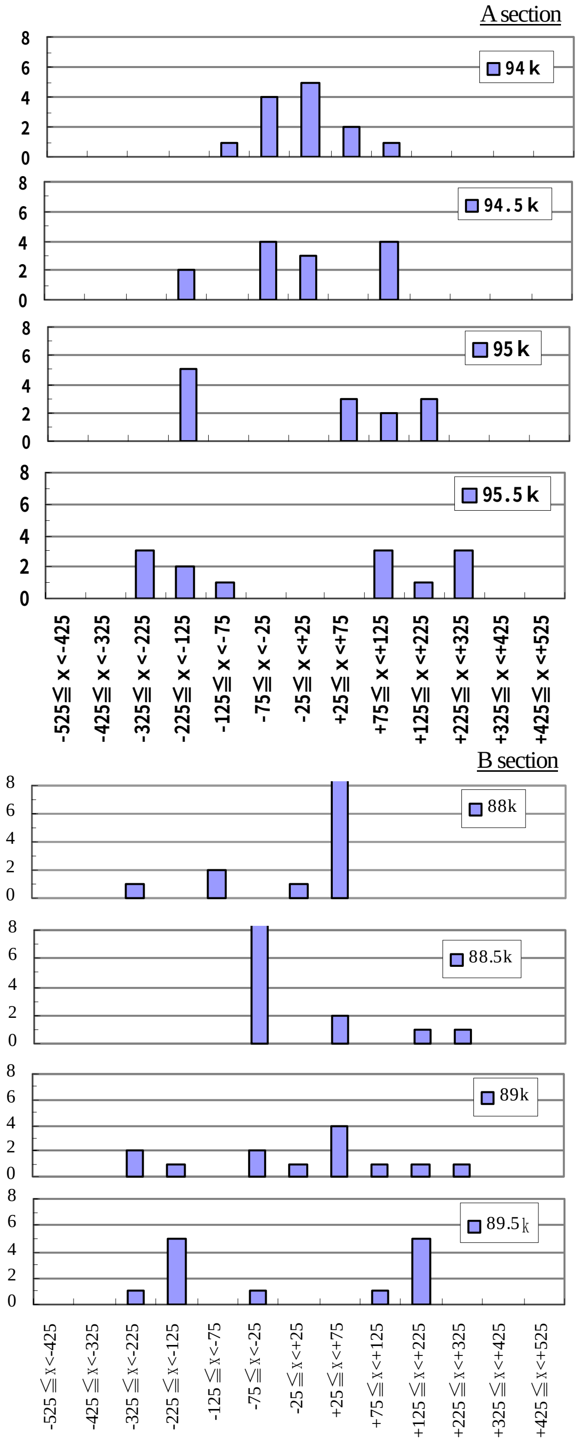

Figure 12. Frequency distribution of the position of deepest river bed in Kinu-river.

Lateral axis is a difference from the mean distance from left bank to the deepest riverbed. Vertical axis is frequency within each range. The measurements were done 13 times during 1963-2001.

Standard deviation of lateral position of deepest river bed between 83k-101.5k using 13 data from 1963 to 2001 is shown in Fig. 11. And it is found from Fig. 11 that the lateral change of thal-weg is little in up-stream section (A section) and large in down-stream section (B section). The figure of thal-weg in A section divides cleanly focus positions and emission positions, and it can be recognized that there are divided reaches, continuously connecting each reach longitudinally, where maximum value of deviation appears at upstream point of one reach and minimum value at down stream point of the same reach. In fact these down-stream points correspond to the existing positions of the stable lateral jam up deposits of large stone. In the down-stream section (B section), above tendency is not clear than that in A section.

As stated above, these causes are related to the scale and the stability of longitudinal jam-up deposit of large stones. Thal-weg in A section are formed under the condition of stable longitudinal deposits composed of larger stones, than those in B section. Fig. 12. shows frequency distribution of the position of the deepest bed in Kinu River.

In A section, the positions of thal-weg at 94k are stable near at center part and then approaches to right and left direction according to shift down stream. This tendency means the developments of thal-weg along right and left bank, and fluctuations of the flowing position also become large due to the changes of stability of longitudinal jam-up deposit of large

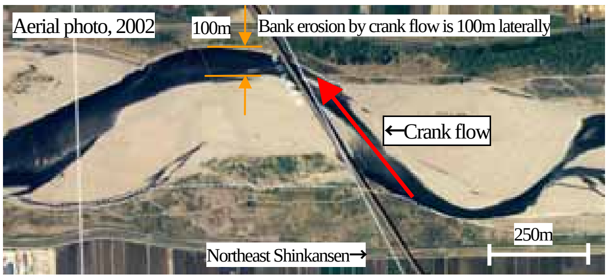

Photo 5. Crank flow of Kinu-river

[Northeast Shinkansen area, 94km]

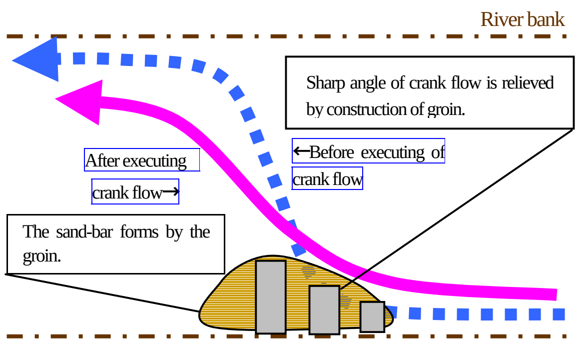

Figure 13. Jetty construction method for relief against crank flow

stones, according to shift down-stream.

Because the scale of the phenomena are larger in up stream section (A section), the scale of crank flow and also the strength of bank attacking concentrated flow becomes larger in A section than in B section.

For example in Kinu-river, at northeast shinkansen area of A section, bank erosion of 100 m laterally in a flood of one time (1day) occurred. Photo. 5 shows the crank flow at northeast shinkansen in Kinu-river. Direct causes of this area are considered as follows; 1) Existence of large-scale lateral jam-up deposit of large stones. 2) Development of thal-weg caused by the construction of straight revetment at left bank. 3) Stability of longitudinal jam-up deposit of large stones is high, and lateral shape is convex clearly. 4) Difference of elevation between left and right bank is large.

In this case, stability of longitudinal jam-up deposit of large stones and two lane flow are recognized even in Fig. 12. As result of description above, severe change of flow to the right bank from left bank is occurred after the extension of thal-weg down stream at left bank and the strong crank flow at developed along and in front of the lateral jam-up deposit of large stones.

V. MEASURE OF CRANK FLOW

Direct bank protection method was adopted in Watarase-river because local erosion came lose to the levee. But the structure of jetty was too heavy, and the straight of bank attacking concentrated flow at sharp angle to the bank aid not to be mitigated. Moreover, environmental problem becomes severe.

Countermeasure for local erosion and environment is urgent to discuss, because the developments of crank flow has recently increased quantitatively and also qualitatively, as discussed Ref. [8]. Basically, then methods are considered as countermeasure for crank flow as shown in Table I.

VI. CONCLUSION

This paper dealt with a new type local erosion along a river bank caused by crank flow which has powerful bank attacking concentrated flow at sharp angle to the bank. Among various patterns of crank flow, crank flow which develops by deformation mainly due to artificial actions is investigated. As original meandering channel system, divergence convergence morphological system was adopted.

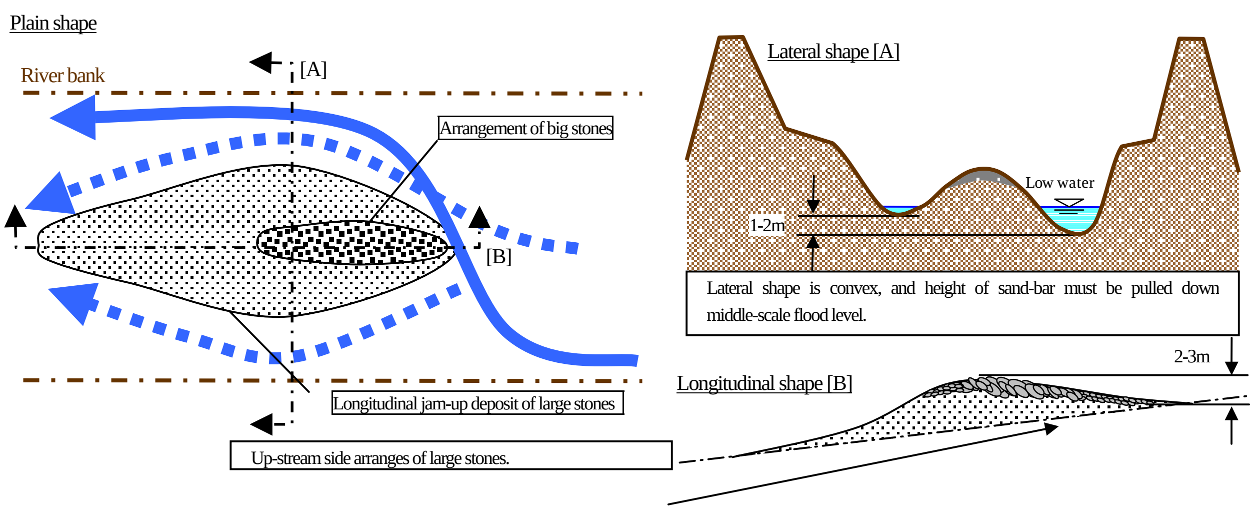

Figure 14. Restoration of double lanes meandering system

Table I. Countermeasures for crank flow

Countermeasures	Construction method	Point of construction method
Direct measure for river bank	Groin, Jetty Revetment, Foot protection, et al	1) These construction method is effective for bank erosion by crank flow. 2) The groins at the bank attacking concentrated points are effective. It is possible to move position of from the front of river bank to the central part of the river.
Relief of cause of crank flow	Relief of sharp angle of the flow	1) Change of shape of a little by using groin, is shown Fig. 13. (Angle of crank flow from sharp angle to loose angle modification.) 2) Small-scale groin system to form sandbar, and loose angle.
Restoration of river channel system	Double lanes meandering system (Longitudinal jam-up deposit of large stones)	1) The restoration of longitudinal jam-up deposit of large stones is examined. 2) Change of flow pattern to two lane meandering from single lane. Velocity at the river bank will be decreased. 3) The large stones are deposited at the upstream side of longitudinal jam-up deposit in other to get stability, is shown Fig. 14.

In Japan recently, channel characteristics has been changing and new type disaster due to bank erosion is increasing, especially by crank flow developed in divergence convergence meandering channel. Therefore, revetment works as the countermeasure for disaster are now constructed at several rivers. Those direct works change the characteristics of the river channel furthermore and promote to change again.

In order to contribute to improve above mentioned urgent practical conditions, field investigation was considered to be important in the study and was made mainly in Kinu and Watarase River. Then, general consideration was made and get following results. Suggestions were also added for the idea of countermeasure, including further problems for studies.

1) General concept of the development of crank flow was clarified in the case of divergence convergence morphological meandering channel system.
2) Local erosion along river bank caused by bank attacking concentrated flow at sharp angle to the bank is a new type phenomenon. This phenomenon has lose relation with the development of crank flow. Especially crank flow caused by deformation of meandering system in a stable divergence convergence channel develops the power to the bank attacking concentrated flow at sharp angle to the bank, in the ways to increase angle, velocity and rate of crank flow discharge.
3) The causes of increase of power to crank flow are as follows; a) degradation by dredging, enlargement of channel and decrease of sediment run off, b) development of thal-weg, extension of thal-weg down stream along constructed straight revetment, c) increase of relative height of bar and its development, growth of grasses and trees on the bar, d) decrease of disturbance due to dam construction, e) destruction of lateral and longitudinal jam up deposit, decrease of big bed materials, decrease of meandering mode from double lane meandering to mono meandering, deformation of original meandering system.
4) Basic structure of divergence convergence channel meandering system is formed based on bed material sifting during flush flood flows. And main characteristics have graded large bed material. Formation of jam-up deposit of large stones causes flat and wide surface up-stream divergence reach, and also steep and narrow convergence reach down stream. Especially, divergence side is constituted with several longitudinal jam-up deposit of large stones, and lateral shape is convex.
5) Crank flow develops mainly in the divergence reach. Scale and power of crank flow depend on the stability of longitudinal jam up deposit of large stones and the scale of convex bar of 3D (at three dimensional) curved surface, these condition bring long extension of thal-weg, big bed elevation difference, and abrupt change when deformation exceeds its critical states.
6) Countermeasure of clank flow is needed to discuss both direct construction method at bank attacking concentrated position and relief of cause of sharp angle of the crank flow. This paper proposed new construction method at relief of cause of crank flow. The other measure is characterized restoration of longitudinal jam-up deposit of large stones in order to recover the double lanes from single lane. This method is also evaluated in the sense of environment such as stone and gravel river beach simultaneously.
7) This study is expected to offer fundamental idea of measure for crank flow.

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