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EXPERIMENTAL STUDY OF SPUR-DIKES DURING FLOODING

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ABSTRACT

In general, rapid rivers transport much sediment in river causing often causes degradation of river beds and scour of river banks.This and leads to deterioration of low-flow channels and dike damage. To prevent these, spur-dikes are used since they are very effective in containing river channels. Spur-dikes are river structures with multiple functions including flow channel establishment, prevention of scour near dikes and revetments,causing sedimentation to change the flow direction away from river banks to the river center. Spur-dikes may also be used to reduce flow velocities.However, much is yet to be learned about the influence and effects of spur-dikes during floods.

INTRODUCTION

In Hokkaido, many steep-flowing rivers remain in their natural states, characterized by dish-shaped cross sections, multiple currents criss-crossing each other, and alignments changing year by year. River improvement work is being carried out on the Satsunai River as is typical of such rivers, including installation of concrete-block spur dikes to prevent scouring and erosion of the banks, and to blend the present multi-current flow into a single, stable course.

Spur dikes are structures to control the local hydraulic action of currents. The two major hydraulic functions of spur dikes are to regulate the velocity of flow (reduce the speed), and to control the course of currents (keep them away from the river banks). At times of flooding, however, much about the influence and effect of spur dikes is still unknown.

This report examines the speed-reducing effect of spur dikes and river-bed evolution at the spur-dike heads under design-flood- discharge flow conditions, based on experiments using a large-scale hydraulic model.

LARGE-SCALE HYDRAULIC MODEL

The spur dikes now being installed in the Satsunai River are tell to unify the currents by pushing them off the river banks, and to prevent scouring and erosion at areas where the currents hit the banks hard, especially during low flow. During flooding, however, water flows through or over the spur dikes. This experiment involves the creation of a 20−year long-term plan for improving the river channel, as shown in Figure−1, in accordance with the river improvement project that is underway on the Satsunai River.

The spur dikes were arranged in such a way as to satisfy almost completely the following conditions, which were established from experiments conducted up to last year: The ratio(L/B) of river width (W) to length of spur dike (L) was more than 0.2; and the ratio (D/L) of spur dike length (L) to distance between spur dikes (D) was less than4. Spur dike models 1/50 the size of real ones were used, and the influence and effects of the spur dikes between $k.p.9.0 \sim k.p.20.0$ during flooding were assessed.

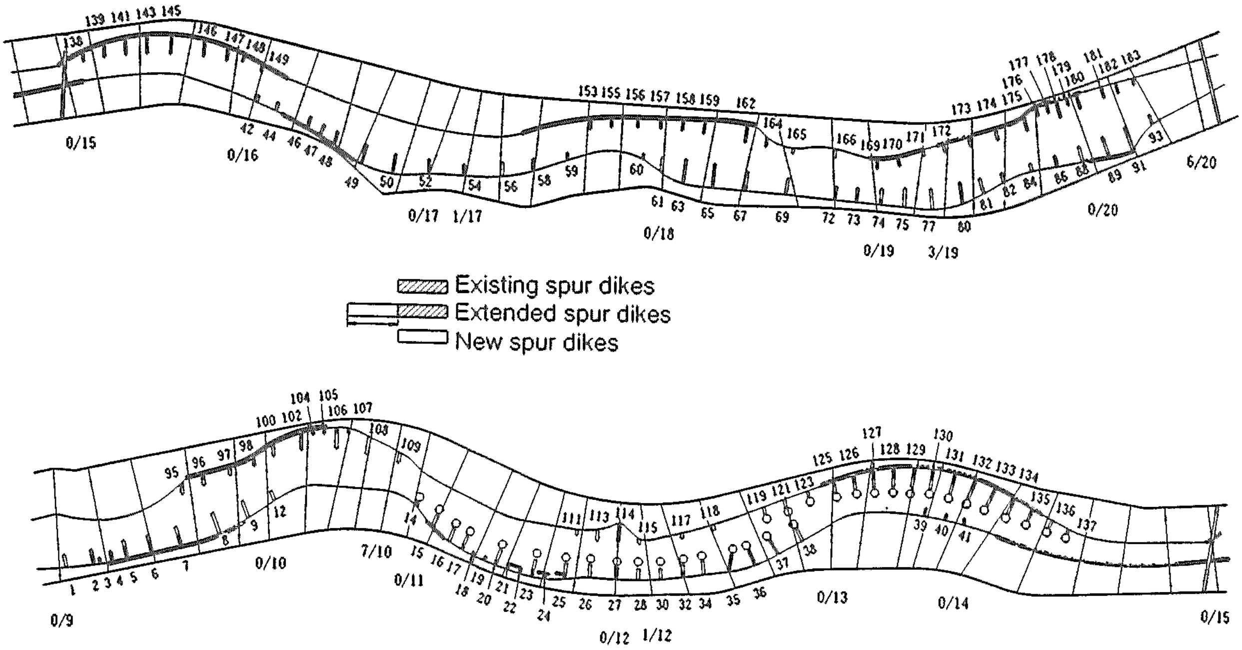


Figure - 1 20-Year Long-Term-Plan For Improving River Channel

Experimental Steps

(1) Adjusting minor bed to design-river-bed height$\Longrightarrow$ (2) Installing spur dikes according to the current plan $\Longrightarrow$ (3) Flowing water for 48 hours$\Longrightarrow$ (4) Installing spur dikes according to the 20-year long-term plan $\Longrightarrow$(5) Flowing water for 48 hours$\Longrightarrow$ (6) Flowing water according to the design-flood-discharge hydrograph.

The two 48–hour water flows were undertaken to create in the model the initial conditions of the river channel, based on the fact that river-bed evolution under actual conditions is determined primarily by snow melt – the exception being times of flooding. A snow-melt discharge rate equivalent to $400m^3/s$ ($23\ell/s$ in the model test) was maintained for the equivalent of two weeks (48 hours in the model test) to prepare an initial river channel. Using design-flood discharge as the experimental condition, it was extremely difficult to record momentary water-level changes. Accordingly, peak water level was determined from the marks left at each $k.p.$ point.

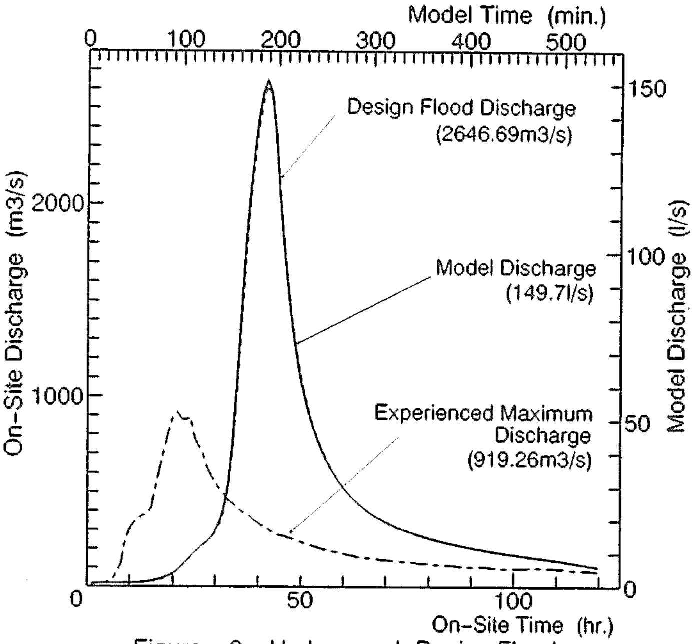


Figure - 2 Hydorograph Design Flood Discharge of Satunai River

Figure–2 is the design-flood-discharge hydrograph of the Satsunai River used in this experiment. The design-flood discharge and maximum experienced discharge are shown in the figure. In both cases,the time from the beginning of flooding to peak flooding was about 10 hours; that is, discharge increased within a short period.

CONTROL OF FLOW VELOCITY (Reduction of Speed)

Photo-1 shows the hydraulic regime at its peak, based on actual data converted for the model test.The photo was taken from about 25 meters above the ground using a radio-controlled helicopter.

.Photo - 1 Design-Flood-Discharge Peak Hydraulic Regime

The picture shows that the main current was running almost in the center of the river channel, in a single flow along the intended alignment of the design-low-flow channel. No tendency was observed for the current to run significantly onto the major bed. This was because each set of spur dikes, which were installed to stabilize the river flow, worked effectively to push the current off the banks, and caused the thalweg to develop at the center of the river channel. As for the velocity of flow, the central portion of the river channel was the fastest; speed appeared to be sbwer between spur dikes installed parallel to the banks. According to kitukawa, in the case of foot- protection spur dikes, water flows through or over most of such spur dikes at times of flooding, and they have the effect of adding roughness to the stream. In this experiment, too, spur dikes were intended to provide roughness against the flow of the current between the spur dikes, controlling the flow velocity (reducing the speed) near the banks. If, therefore, the roughness effect of spur dikes resultsin controlling the flow velocity (reducing the speed), then severl things must follow. the water level above spur dikes that are densely installed, or above spur dikes located at the upstream end, should increase, because the spur dikes act as weirs. On the other hand, where spur dikes are not densely installed, or near the middle of a set of spur dikes, and also near the downstream end, the water level should be lower.

In Figure-3, in order to demonstrate the tendencies mentioned above, the slopes of the water surface (calculated from the water-level marks above each spur dike) were calculated. The water depths in the figure are depths from the design-river-bed height, which were found by subtraction. In the relationship between increasing and decreasing water depths shown in the figure, it can be seen that the water depth above each spur dike tended to be slightly higher than the water-mark points. This may be because, as the water passes over the spur dikes, the spur dikes act as weirs,and, as a result,the flow velocity is reduced. According to photo-1and Figure-3, if spur dikes are considered in terms of their contributed roughness - dividing roughness and reduced velocity of flow into two major types, pier type and pile type-the spur dike arrangement in this experiment was equivalent to pier-type roughness. As to pier-type roughness, many people through various experiments have already determined that the ratio of pier height to distance between piers, and the ratio of pier height to water depth, are important factors. For spur dikes, too, therefore, the ratio of spur dike height to distance between spur dikes, and the ratio of spur dike height to water depth, are considered to have significant inpostance to the reduction of velocity.

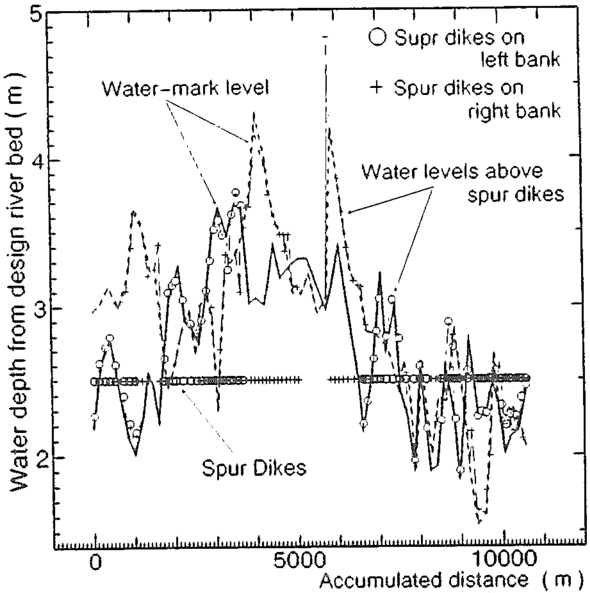


Figure - 3 Water-Level Changes by Installation of Spur Dikes

Figure-4 and 5 show ratios of spur-dike height to distance between spur dikes, and of spur-dike height to water depth, in this experiment.Examples of a spur-dike installation plan and implementation at an actual site will be introduced below.

Figure–4 shows the ratios (D/hg) of spur-dike height from the design river bed to the distance between spur dikes. From the figure it can be seen that in this experiment spur dikes were installed, in most cases, at intervals of about 40 to 50 times the spur-dike height. According to on-site investigation at the Satsunai River in 1981, intervals between spur dikes were, in many cases, around 30 to 50 times the spur dike height. In other words, the spur dikes in this experiment were installed at almost the same intervals.

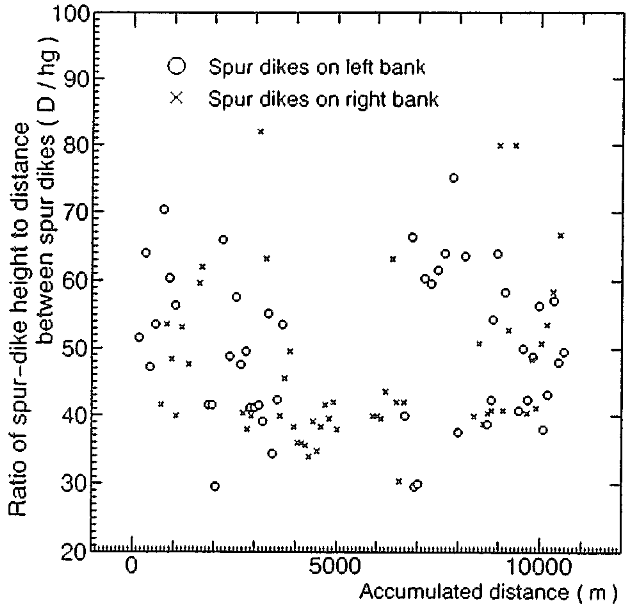


Figure – 4 Relationship between Spur–Dike Height and Distance between Spur Dikes

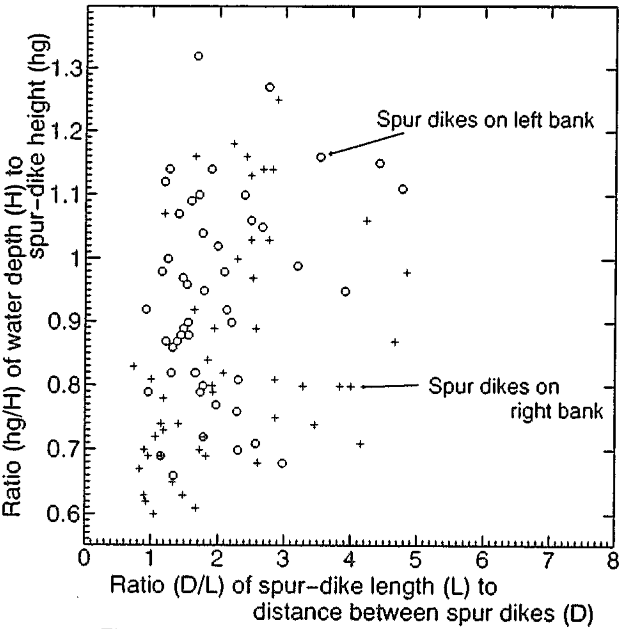


Figure – 5 Relationship between hg/H and D/L

In Figure–5, the horizontal axis is the ratio (D/L) of spur-dike length to spur-dike interval, and the vertical axis is the ratio (hg/H) of spur-dike height (hg) to water depth (H). The ratios D/L in this experiment are mostly in the range of 1 $\sim$ 3; on-site investigation also revealed that D/L was in many cases in the range of 1 $\sim$ 3. But, as to design-minor-bed cross section, the on-site ratios of spur-dike height (hg) to water depth (H) ranged from 1.8 to 2.1; while, in this experiment, they fell between 0.8 $\sim$ 1.4 – perhaps because minor-bed width was greater than the design-minor-bed cross section. Additionally, from the data, there were places where water did not flow over the spur dikes.

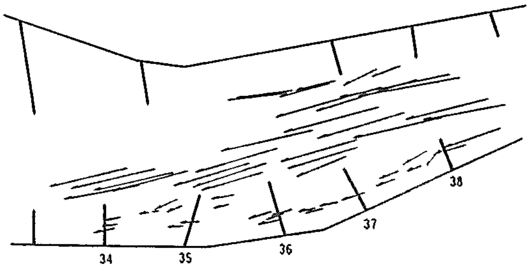


Figure – 6 Vector Diagram of Velocity of Flow near Spur Dikes(phto analysis)

For those cases, as shown in Figure–5, where the spur-dike height was greater than the water depth, the speed-reduction effect of the spur dikes was investigated.

Figure–6 is a vector diagram of flow velocity made by photo analysis was done. The velocity at the main-stream portion was about $7.8m/s$ (value converted from actual site), and the velocity between spur dikes was from about 1.3 $\sim$ $1.6m/s$(value converted to actual site), showing that the flow of the main current became faster, and the velocity between spur dikes was reduced. Akikusa$^{2)}$ et al. conducted a test where water depth became less than 10 times spur-dike height, through which they concluded that, by selecting appropriate river-bed locations, logarithmic distributions and the theory of equivalent roughness can be applied. Adachi$^{3)}$ gave the following formula for pier-type roughness based on his own and other's experimental results:

$$\frac{u}{u_* H} = 1.50\log\frac{s}{k} - 1.91 + \{5.75 + 0.12(\frac{s}{k})^{0.8} \log\frac{H}{k} \qquad (1)$$

[formula]

s = Interval between piers, k = Height of pier, H = Water depth,
$u*$ = Friction velocity, u = Average velocity,
Provided, however, that $8 < s/k < 160$.

From the above formula, relative roughness and relative roughness intervals are found, from which the resistance term u/u_*H is calculated. Although there were differences in experimental conditions, the resistance term $u/u * H$ (average velocity between spur dikes) of the spur dikes in this experiment was obtained using the above formula. The spur dikes at six points were subject to the calculation points - $Nos.$35, 36, 37, 38, 61 and 63 (refer to Figure−1). Distance between piers s in the formula was the distance from the center of a spur dike on the upstream side to the center of the next one, at their heads. Spur-dike height k was from initial river-bed height (average river-bed height after flowing snow-melt discharge) to the crown of the spur dike. Water depth H was from the water level over the spur dike (which was found by subtraction) to the initial river-bed height.

In Figure−7, ○ are calculated values, and ● are values obtained from analysis of photos taken from the radio-controlled helicopter. Water depths from the spur dike crowns to the water surface at spur dikes $Nos.$35, 36, 37 and 38 were 0.75 ~ 1.27m; differences of 0.17 ~ 0.20m/s were found between the photo-analytical and calculated values.

At spur dikes $Nos.$61 and 63, where water depth from the spur-dike crown to the water surface was 20 ~ 40cm, average calculated values for velocity of flow were too low to be considered. It is, however, possible to find average velocity between spur dikes by the above formula, when water depth (from the spur dike crown to the water surface) is more than 1 meter. This time, though, there was not enough analytical data; in addition, average velocity will vary with the means of determining water depth and spur-dike height, as well as with the impermeability, bending, and other spur-dike factors. After collecting more data, further consideration of these issues is necessary.

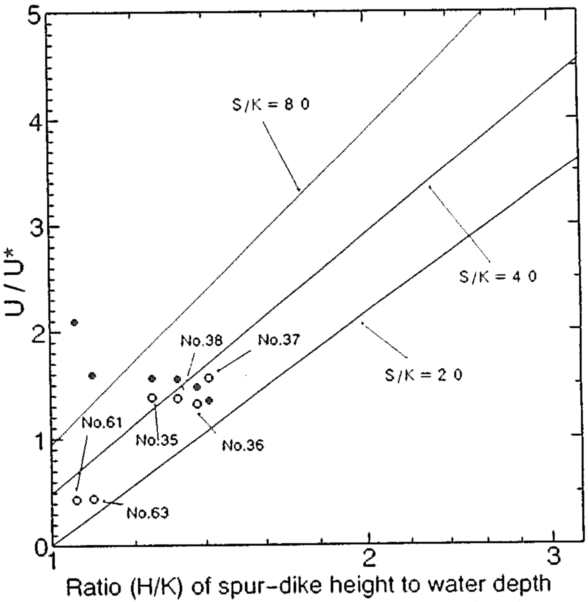


Figure - 7 Spur-Dike Resistance (u/u*H)

RIVER-BED EVOLUTION AT SPUR DIKE HEADS

Photo - 2 Initial River-Bed Condition (after Snow Nelt Discharge)

Photo−2 shows the initial condition of the river bed after the second 48-hour water-flow session (snow-melt discharge). Looking at the river-bed condition, there is a single line of sand bars in the area of $k.p.$14.0 ~ 15.0, where revetment work had been done and where the minor-bed width was almost equal to the design-minor-bed width. Elsewhere, multiple sand bars and interwoven multiple currents are shown.

Photo−3 shows the river-bed condition after a flow of design-flood- discharge. This condition and location of the thalweg almost match those of the design-flood-discharge peak shown in Photo−1, and the river channel, with a single line of sand bars, is more distinct than the one after the snow-melt-discharge flow shown in Photo−2. This was because the multiple currents had been unified into a single flow by the spur dikes, and, as a result, alternating sand bars developed to create a stable river channel. Generally, according to Photo–3, water flowed along the spur-dike heads, and was the main current at design-flood discharge. In those circumstances, areas around the spur-dike heads were scoured significantly.

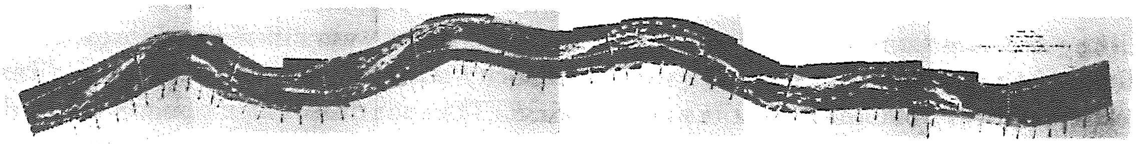
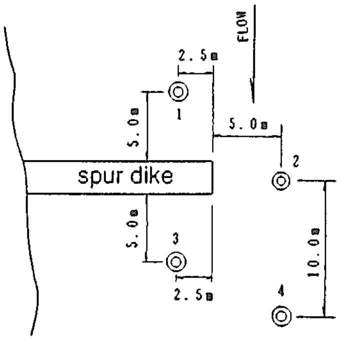


Photo - 3 River-Bed Condition after Design Flood Discharge

Accordingly,the maximum scour depth was also measured using rings as shown in Figures–8 and 9 at areas shown in Figure–1. In this method, rings settled as the areas beneath them at the spur- dike heads were scoured by the flowing water; when sedimentation began in the area, sand accumulated on the rings. After the test, sediment was removed down to the rings to measure the maximum scour depth.



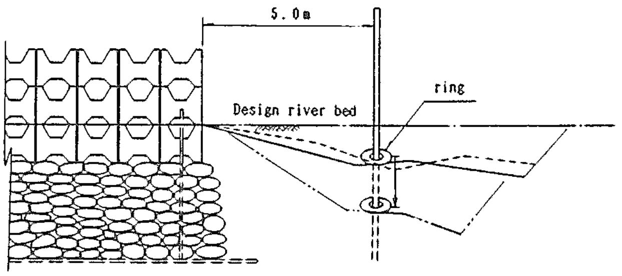


Figure - 8 Plane View of Scour-Obuservation Areas

Figure - 9 Cross Section of Scour-Observation Areas

The results of tests on two groups of spur dikes are shown in Figures–10 and 11. Spur dikes from *No*.14 ~ 38 on the left bank, and from *No*.119 ~ 137 on the right bank, were the subjects of the tests.

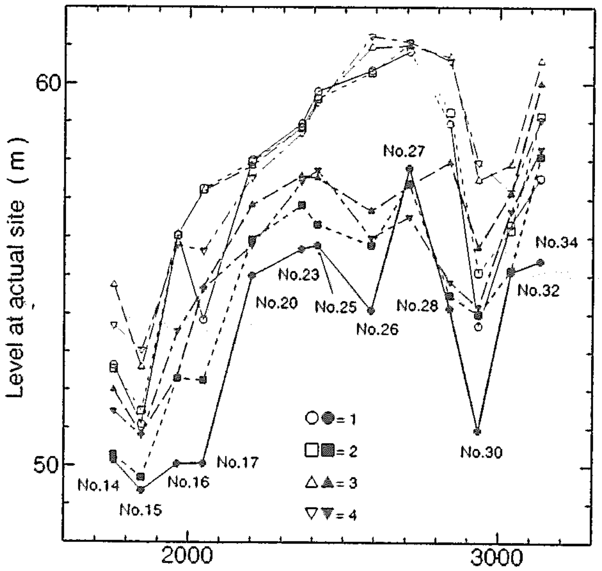


Figure - 10 Scoured Condition of Each Spur Dike(Left Bank)

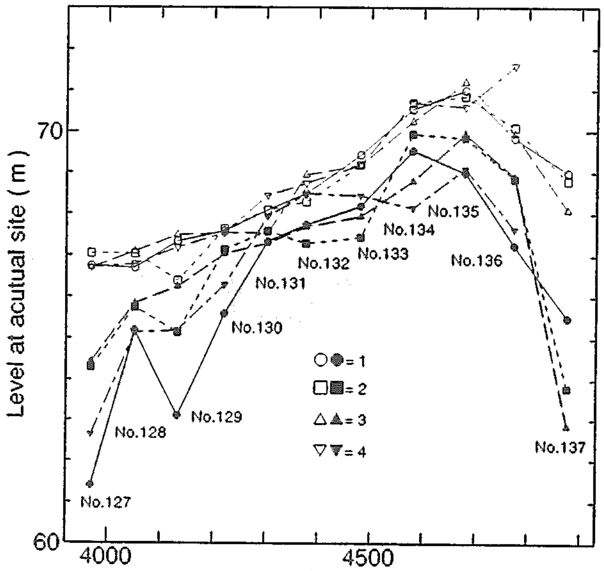


Figure - 11 Scoured Condition of Each Spur Dike (Right Bank)

According to Figures–10 and 11, although there was some difference in degree of scouring depending on the angle of water-flow impact, etc., generally speaking the order of scouring depth from great to small at each spur dike was 1, 4, 2 and 3. The reason for the large amount of scouring at ring 1 is that flowing water hits the spur dike to create a right-angle current. At ring 4, scouring is the result of the spur dike's current- control effect – pushing the current off and toward the center. Ring 2 is at a spot where the spur dike both reduces the current speed and controls the current flow; although there was a difference in the angle of flow impact, compared with ring 1, a right-angle current was produced to scour the spot. Ring 3 was within a dead-water area behind the spur dike, where velocity of the flow was reduced, and , as a result, there was not much scouring. There had been concern that the spur-dike heads would collapse forward in the area of ring 2, because of the scouring away of the base of the spur dikes. Changes to the initial river bed in these areas, following the flow of design-flood discharge, are shown in Figures–12 and 13.

Figure–12 shows the initial river-bed height, maximum scour depth, and river-bed height after the design-flood-discharge flow, for the left-bank spur dikes from *No*.14 to *No*.38. Maximum scoured depth at the spur dike heads ranged widely, from 1.05 to 3.75 meters. At spur dikes *No*.26 and *No*.28, scoured depths of 4.50 ~ 5.00 meters were seen.

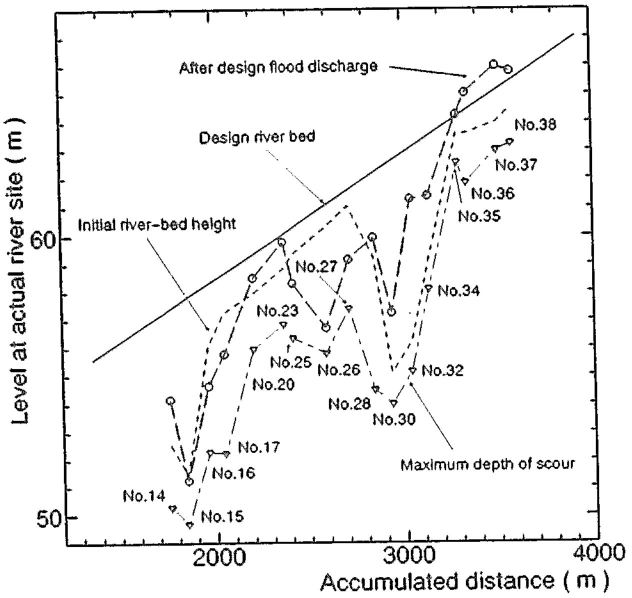


Figure - 12 River-Bed Evolution at Spur-Dike Head Areas(Left Bank)

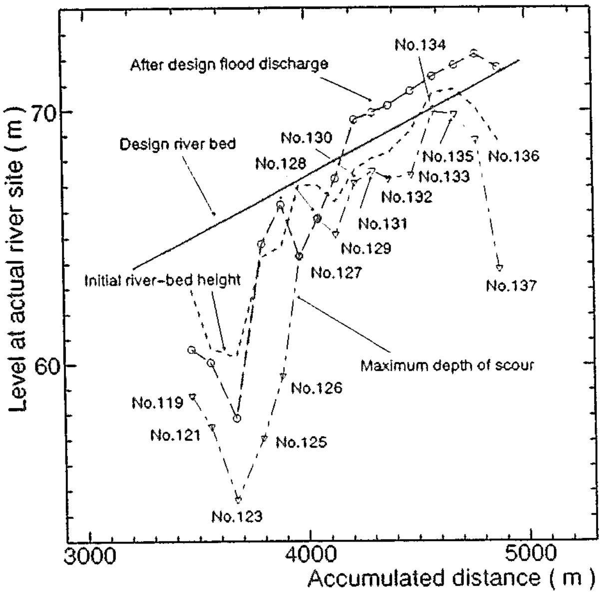


Figure - 13 River-Bed Evolution at Spur-Dike Head Areas (Right Bank)

Figure–13 shows the results for the right-bank group of spur dikes, from *No*.119 to *No*.137. As a whole, compared to the left bank, maximum scouring on the right bank was shallower, but there were some areas, such as at spur dike *Nos*.119, 121, 123, 125, 126 and 137, where maximum depth was between 4.25 and 7.15 meters. According to both sets of figures, moreover, at most of the spur dikes, the river bed after the flow of design-flood discharge was covered with sediment and had become higher than the initial river bed; at some places sediment was deposited higher than design-river-bed height. According to the results of an on-site survey near groundsills using a device to record scouring by Yamashita[4] et al., the evolved river bed returns to its original condition. In this experiment using a large-scale model, the same phenomenon was observed near the spur dikes. This was because the river bed was scoured to the maximum at the time of the design-flood discharge, but, as the velocity was reduced, tractive force diminished, too, and material transported from upstream began accumulating. There are, however, areas where the scoured river bed did not return to its initial condition, and it is likely that those areas were subject to a continuous water impact. In order to determine the kinds of places subject to scouring and impact, a planar depiction was created for discussion.

Figure–14 shows the river bed after a flow of design-flood discharge. The bed was scoured where the main current flowed,and sand bars developed on both sides of the main current.Sand bars also formed at the spur dike heads, which, as a result, created a river channel with close to a single line of sand bars. Among the spur dikes upstream on the right bank (spur dike *Nos*.119 ~ 137), however, the areas at spur dike *No*.119 to *No*.126 were the most scoured and are the areas most heavily hit by water. The line of the main current at that time was a curved segment of about 1,250 meters, with a meander angle of 20 ° ~ 21 °; the scoured area was at a point immediately before the current line turned in the other direction. The ratio of scour depth to water depth was generally 0.6 ~ 0.8; spur dike *No*.125 was the maximum scoured location, with a ratio of scoured depth to water depth of 1.2.

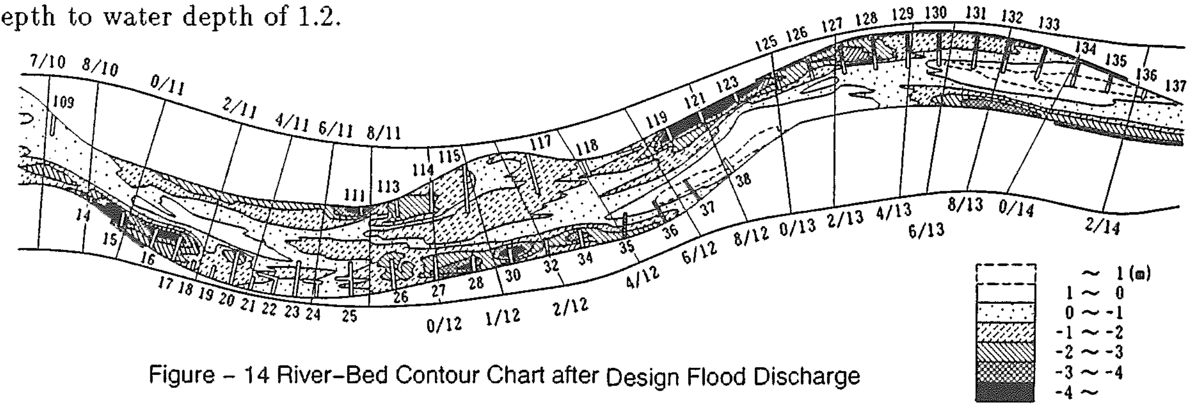


Figure - 14 River-Bed Contour Chart after Design Flood Discharge

As to the spur dike group on the downstream left bank (*Nos*.14 ~ 38), the areas near spur dike *Nos*.16 and 17, and *Nos*.25 ~ 28 were thought to be the hardest hit by water. The line of the main current was a curved segment of about 1,600 meters, with a meandering angle of 23 ° ~ 25 ° .The ratio of scoured depth to water depth was generally 0.8 ~ 1.0 at these areas. The maximum scour depth was at spur dike Nos.17 and 26, with ratios of scour depth to water depth of 1.1 ~ 1.2. The scoured areas were at points just before the top of the curve, and also immediately before the current line changed direction.

In this experiment, it was clear that spur-dike head areas where current tends to hit hardest are just before a meandering current changes its direction, and that the scoured depth was generally 0.8 ~ 1.0 times the water depth, with the maximum ratio being 1.2 times the water depth.

CLOSING REMARKS

In this experiment, spur dikes that were effective during low flow at maintaining a river channel by controlling currents and moving them in the center direction, were also capable of reducing velocity near the banks, at times of flooding when river water flowed over the spur dikes, by their contributed roughness. It was also found that the maximum scour depth at the spur dike heads became greater when discharge was larger, such as at flooding and other times, but the river bed returned almost its original condition after the flooding.

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