EVALUATION OF THE EFFICACY OF WATER CHANNEL PLANNING FOR THE NAGAOKA CITY AREA OF THE SHINANO RIVER

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Abstract: An effective flood-control strategy for mitigating flow attack points in a meandering river with a steep bed gradient and alternate bars is to preserve the floodchannel and stabilize the water course. In the Nagaoka City Area River Plan, main channel alignment was determined according to the results of hydraulic model tests, and training levees were built as the primary means of stabilizing the main channel. To assess the channel-improvement efficacy of these works over the 25 years that have passed since the project began, the authors used the results of field observations, model tests based on the adopted plan, and computational analysis. This paper compares and considers the actual observed effectiveness of the flood control works in the river and the results of model tests and numerical analysis with regard to main channel planning, bed evolution, flow attack point mitigation, and other factors.

Keywords: flood control work, training levee, field observation, hydraulic model test, numerical computation, flow attack point mitigation, bed evolution

1. INTRODUCTION

The Shinano River has a drainage basin area of 11,900 km^2 and is 367 km long, making it one of Japan's largest rivers. The river's Nagaoka section, defined as that between the 15.5 km and 22.5 km upstream points of the Okozu Diversion Channel, runs through urban Nagaoka City and so is one of the most important sections with regard to flood control. This is also where the waters of the Shinano River enter the Niigata Plain after descending through mountainous terrain. Consequently, the bed gradient is steep and sharply changes in this area, with extensive meandering and longitudinal variation in main channel width and inter-levee distance, accompanied by alternate bars and deep bed scouring. This section is also characterized by a long period of snowmelt runoff, typical of snow-accumulation regions.

Consequently, river courses have been poorly managed, with numerous flow attack points and extensive damage to revetments and other river structures. Before implementing river planning to reduce this flood danger through bed stabilization, hydraulic model tests were conducted to assess main channel alignment, and methods and procedures for channel improvement works.[1), 2)] Based on these results, full-scale work was begun around 1975. Roughly 10 years later, changes in actual river conditions brought about by the flood control works were compared to the results of hydraulic model tests[3)]. Another thirteen years later, further investigation showed that the flood control works had indeed been effective.

This paper compares and considers the actual observed effectiveness of the flood control works and the results of model tests and numerical analysis with regard to main channel planning, bed evolution, flow attack point mitigation, and other factors. In particular, we compare the experimentally predicted and observed effectiveness of the training levees that characterize this river plan and attempt an assessment using numerical analysis of the flows.

2. RIVER PLANNING FOR THE NAGAOKA CITY AREA

2.1. RIVER HYDRAULIC PROPERTIES

The Nagaoka City Area of the Shinano River is situated in the alluvial fan region of the Niigata Plain, and its alignment is characterized by extensive meandering, particularly at the 18.25 km point, near the Chosei Bridge. The bed profile undergoes a sharp change in gradient at the 17.5 km point, from 1:650 upstream to 1:1,200 downstream.

Temporal change in mean bed level exhibited a degrading tendency in the years 1965–1975 but has been fairly stable recently. Inter-levee distance ranges from a maximum of 1,000 m to a minimum of 800 m; the main channel width is 250–450 m.

Upstream, bed material comprises gravel with a mean particle diameter of 40–50 mm and transitions to sand 0.1–0.5 mm in diameter beginning at the 12.0 km point. The section is categorized as a Segment 2-1 gravel waterway, intermediate between alternate sandbars and double-row sandbars. Flow attack point positions (Figure 1) are nearly stable, and the particularly severe ones are at Mizunashi (21.5 km, right bank), Shibumi River confluence (19.5 km, left bank), Kusozu (18.0 km, right bank), and Zao (15.0 km, right bank).

The average annual maximum discharge recorded at the Nagaoka Observation Station is approximately 4,000m^3/s (for the years 1978–1998). The average maximum discharge for the snowmelt season can be as great as 2,400m^3/s for as long as 1 month. Snowmelt discharge accounts for 30–50% of total annual discharge.

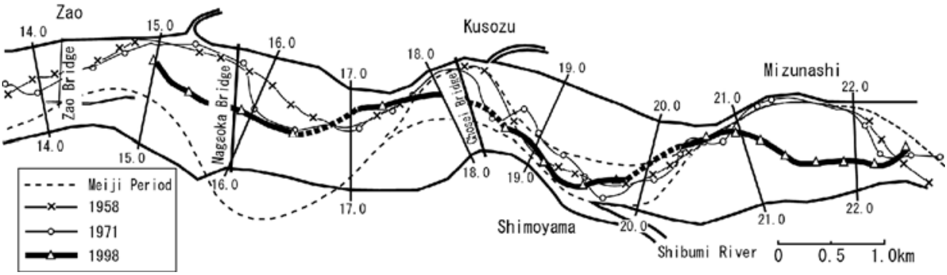

Figure 1 Plan view of Nagaoka district and time change in the deepest riverbed locations

2.2. PLANNING, POLICIES AND HYDRAULIC MODEL TESTS

The primary objective of the Nagaoka City Area River Plan is to mitigate flow attack points; other policies are as follows:

a.) Levee alignment is to remain unchanged.

b.) To correct the main channel's extensive meandering, a compound cross-section is to be utilized, mitigating dangerous attack points and permitting utilization of the flood channel.

c.) Main channel width and depth should be 320 m and 4.5–5 m, respectively, to handle a discharge of up to 4,000 m^3/s, which is expected to occur once every 2–3 years.

d.) The first proposal for main channel alignment is to follow temporal change in the water course and shift the attack points toward the channel's center to the extent possible. The best proposal shall be selected according to the results of hydraulic model test.

Main channel stability was examined by means of hydraulic model tests with a mobile bed having a distortion scale of 1:100 on the horizontal and 1:70 on the vertical. Testing of the first and second proposals for main channel alignment suggested that these main channel designs would not satisfy the requirements. The third proposed design was indeed found in experiment to smooth the main channel flow and to greatly alleviate damage to the flood channel. It was therefore decided to adopt the third proposal and construct a flood channel to protect the banks from flow attack. The entire project involved constructing revetments and deepening the main channel to protect the flood channel, and constructing training levees to form the flood channel and mitigate flow attack.

The decision was also made to perform model tests to assess the work sequence in which the various elements of the project were implemented, identify the position and range of the flow attack points, determine the post-completion effects of flow attack mitigation, and assess the construction method.

Full-scale work began in 1975 and by 1992 was approximately 70% complete, with no significant change in either the work itself or its sequence relative to the initial plan.

3. POST-CONSTRUCTION CHANNEL CHANGES AND COMPARISON WITH THE RESULTS OF HYDRAULIC MODEL TEST

Figure 2 shows peak discharges associated with major floods since 1979. For three consecutive years (1981–1983), large floods ranging from 7,000 to 8,300m^3/s occurred, compared with the planned flood discharge of 11,000m^3/s. There followed a long period of no significant flooding other than the annual periods of snowmelt runoff. In 1998, however, a flood of 6,700m^3/s was recorded. Figure 3 shows changes in the main channel between 1977 (before full-scale improvement works commenced) and 1995 as determined from aerial photographs. Before the improvement works, the channel bed had complex meandering alignment and many large sandbars, and so there were flow attack points where the main current directly struck the levees. After the improvement works, in contrast, the main channel is more distinct, and the flow attack points (e.g., at Mizunashi and Kusozo) have been mitigated. Figure 4 (a comparison of changes in the water channel and in the cross-sectional form between 1975 and 1998) shows pronounced mitigation of flow attack, including a higher bed level near the levee foot at a flow attack point and the movement of deepest bed level from the levee toward the center of the channel.

Figure 5 compares the flow regime as determined from model tests with the actual water course as it appeared in 1999, and permits the conclusion that the model test in general accurately predicted the 1999 channel flow. Differences exist at a detailed level, but these are attributable to such factors as progress of the improvement works.

4. VALIDATING THE EFFICACY OF TRAINING LEVEES

4.1. TRAINING LEVEE EFFICACY AND SEDIMENTATION

Longitudinally oriented training levees placed in front of flow attack points utilize the forces of nature to correct the watercourse, maintaining the main channel in a favorable condition and reducing the current's velocity behind it. In this section of the Shinano River, training levees formed the heart of this plan to construct and maintain a flood channel by utilizing the sedimentation that occurs in the long snowmelt runoff period.

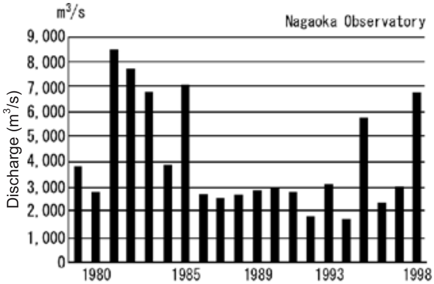

Figure 2 Discharge of previous floods

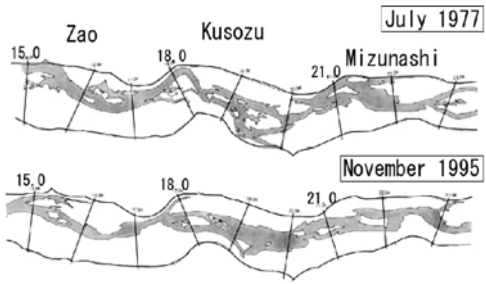

Figure 3 Changes in the main channel

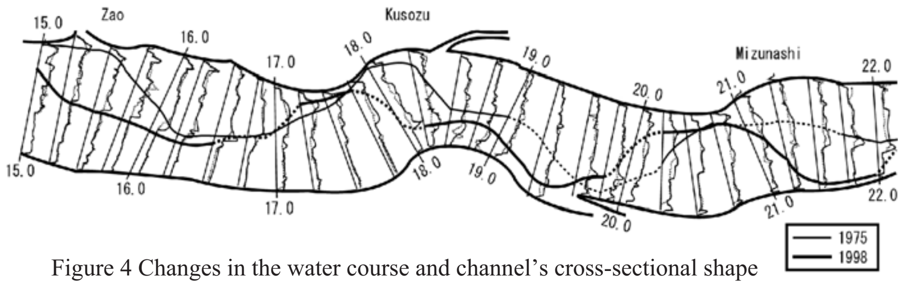

Figure 4 Changes in the water course and channel's cross-sectional shape

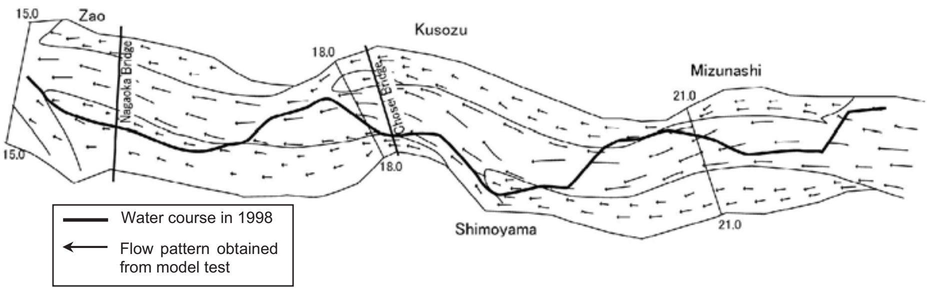

Figure 5 Comparison between hydraulic model test results and measurement data

The training levee structure comprises three layers of two-ton irregularly shaped blocks placed in 12-m-wide rows on a 20-m-wide fascine mattress. The height was set at slightly less than the planned flood level in anticipation of sediment deposition at annual maximum discharge.

4.1.1. Mizunashi Area (21.0–22.5 km, right bank)

After construction of main-channel revetments on the left bank and groins at the right-bank flow attack points, training levees were built in the Mizunashi Area beginning in 1977. Sedimentation on the bank side of the training levees eventually formed the flood channel, where vegetation now grows (Figure 6). This resulted in movement of deepest bed level from near the right-bank levee to the main channel's center.

4.1.2. Kusozu Area (18.0–18.5 km, right bank)

Work here includes revetments on the main channel's left bank, underpinning for the piers of the Chosei Bridge, and deepening of the main channel to alter the watercourse and the flow direction. Next, training levees were built along the right bank starting in 1983. Work was completed in 1992, including aligning the edge of the leave to the bank.

Because of the river–tributary confluence as shown in Figure 7, the training levee was built to create a closed, V-shaped area where sediment has accumulated. The flow attack point has moved farther downstream, and the main flow has remained concentrated in the channel center, even during recent flooding. Furthermore, the position of deepest bed level has moved from the right bank toward the center.

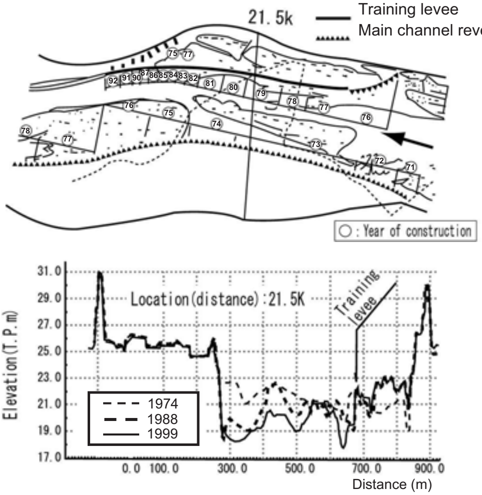

Figure 6 Effects of the training levee constructed in Mizunashi

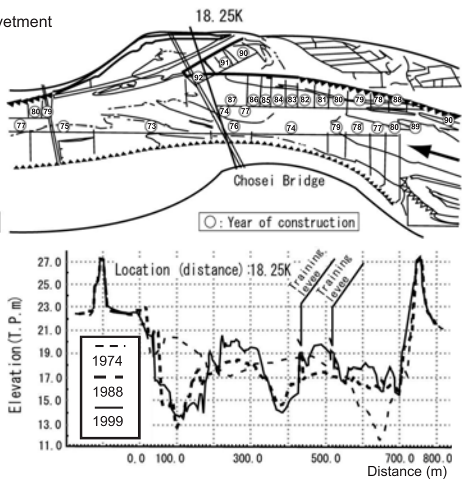

Figure 7 Effects of the training levee constructed in Kusozu

4.1.3 Zao Area (15.0–16.0 km, right bank)

In 1986–1988, a training levee was built, and large point bar on the opposite bank was dug out, altering the water course. Although the position of deepest bed level remained near the embankment toe, bed level in general has risen over 2 m, indicating that the problem of bed scouring has been eliminated. Overall, the main flow has moved toward the channel center (Figure 8).

Data on temporal change in sedimentation behind the training levees built in the Mizunashi, Kusozu, and Zao areas (Figure 9) show faster rates of sedimentation in the years 1975–1985 and 1995–1998 (although the training levees were not all built in the same timeframe). This is indicative of a significant

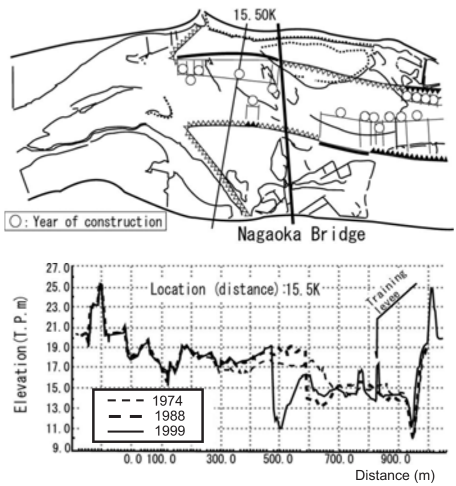

Figure 8 Effects of the training levee constructed in Zao

relationship between sedimentation and flooding.

4.2. RESULTS OF NUMERICAL ANALYSIS

Training levee efficacy was also assessed computationally through flow analysis based on plane two-dimensional unsteady flow calculations. Figures 10–12 show the planar distribution of discharge flux resulting from a simulated discharge of 8,300m^3/s (equivalent to the maximum value recorded after 1945) in two scenarios: 1974 (before the river improvement works began) and 1992 (when the works were essentially completed). Discharge flux was calculated as the product of velocity and depth and so is equivalent to unit-width discharge.

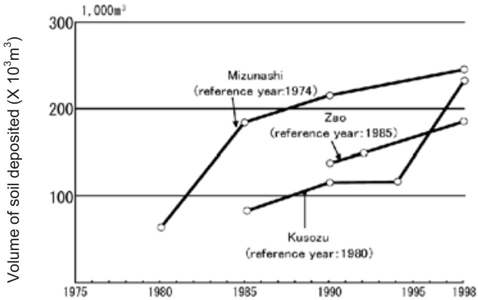

Figure 9 Changes with time in volume of soil deposited behind training levee

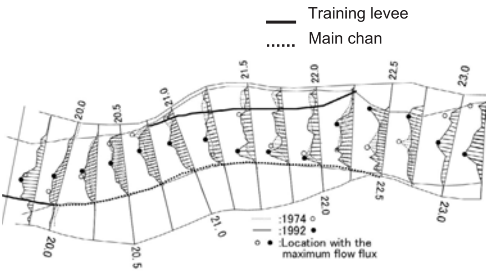

Figure 10 Numerical analysis results (Mizunashi)

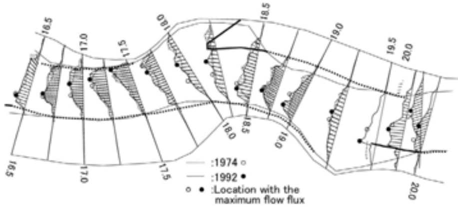

Figure 11 Numerical analysis results (Kusouzu)

Computational results show that in the Mizunashi area, discharge along the embankments in the 1992 scenario was approximately 50% lower than in the 1974 scenario, mitigating the flow's attack force on the embankments. In addition, the location of maximum discharge flux near the 21.0 km point had moved from the embankment to the channel center. In the Kusozu area, discharge at the embankments was 30–50% lower, indicating a similar mitigation of flow attack points. In the Zao area, discharge along the embankments decreased roughly 50%, main-channel discharge increased, and the flow was more rectilinear.

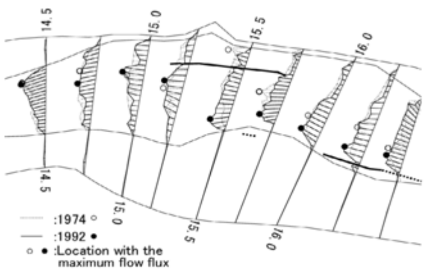

Figure 12 Numerical analysis results (Zao)

Regarding bed evolution in a period of frequent flooding (1980–1985), Figure 13 shows actual scouring in the Mizunashi area and computationally obtained bed evolution. The calculation results in general agree with the observed results, in which the site of extensive scouring roughly corresponds to the location of maximum discharge flux shown in Figure 10. In addition, the results of numerical simulation on bed variation were in generally good agreement with measurement results.

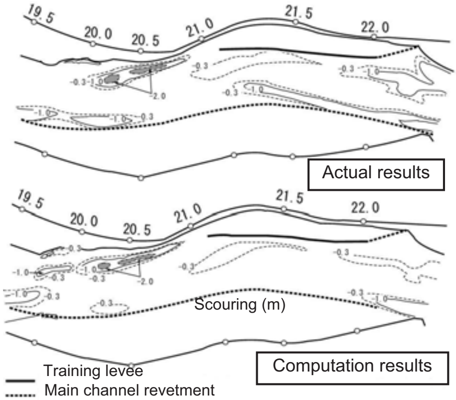

Figure 13 Bed variations in Mizunashi

5. CONCLUSIONS

The principal conclusions of this paper are as follows.

(1) Field observations clearly showed that the training levees—intended to utilize sediment deposition during flooding—were effective in stabilizing the main channel and mitigating flow attack points.

(2) General agreement with the results of field observations verified that model test is an effective technique for use in river planning having the objective of main channel stabilization.

(3) Plane two-dimensional unsteady flow computations verified flow attack mitigation. Other basic characteristics (e.g., flow concentration) revealed by the computations also agreed with actual bed evolution.

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