CHAPTER 3  FEASIBILITY DESIGN OF SEDIMENT STORAGE RESERVOIR

3.1 Design Condition and Criteria

The sediment storage reservoir structures subject to feasibility design are the new spillway, closure dike and overflow dike. The layout of the facilities is shown in Figure 3.1.1. Design conditions and criteria are set out as listed in Table 3.1.1. Design water levels for design of the new spillway structure are illustrated in Figure 3.1.2.

Table 3.1.1 Design Conditions and Criteria

<table>
<thead>
<tr>
<th>Structure</th>
<th>Item</th>
<th>Condition and Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) New Spillway</td>
<td>Type</td>
<td>Front overflow weir</td>
</tr>
<tr>
<td></td>
<td>Elevation of Inlet</td>
<td>EL.127.0 m (Design deposits level)</td>
</tr>
<tr>
<td></td>
<td>Design discharge</td>
<td>Q=1,270 m³/s (at PMF)</td>
</tr>
<tr>
<td></td>
<td>Water level</td>
<td>EL.139.1 m</td>
</tr>
<tr>
<td>(2) Closure Dike</td>
<td>Crest elevation</td>
<td>EL.138.3 m (Surcharge water level)</td>
</tr>
<tr>
<td></td>
<td>Elevation of foundation</td>
<td>EL.127.0 m (Design sediment deposits level)</td>
</tr>
<tr>
<td></td>
<td>Width of crest</td>
<td>W=10.0 m</td>
</tr>
<tr>
<td>(3) Overflow Dike</td>
<td>Crest height</td>
<td>Crest Height EL.136.0 m</td>
</tr>
<tr>
<td></td>
<td>Design discharge</td>
<td>Q=550 m³/s (at SHFD)</td>
</tr>
</tbody>
</table>

Sediment storage reservoir: EL. 138.1 m
Main reservoir: EL. 137.8 m.

Note: Design discharges are discussed in subsection 3.1.6.
Source: JICA Study Team

3.2 New Spillway

The new spillway is planned at the right abutment of the Wonogiri dam. Layout plan and profile of the new spillway are shown in Figures 3.2.1 and 3.2.2 respectively.

Required function of the new spillway is to release the design flood discharges safely and to smoothly flush out the sediment-laden flood inflow from the Keduang River as well as the sediment deposits in the sediment storage reservoir. Feasibility design of the new spillway is described as follows:

Figure 3.1.2 Design Water Levels for Design of New Spillway
3.2.1 Layout Plan of New Spillway

(1) Concept of Plan

Concept of layout plan are as follows:

The concept of layout plan is as follows:

a) The new spillway is to be constructed within the premises of PBS or PJT I Bengawan Solo.

b) The inlet of the spillway is placed about 100 m in front of the Wonogiri dam axis to avoid giving negative impacts to the dam body during the construction and the operation after the completion.

c) A training channel is placed from the inlet of spillway to the end of curved portion of the spillway. Gradient of the channel is about 1/108.

d) A chute channel is placed from the end of training channel to the inlet of the energy dissipater. Gradient of the chute channel is 1/108, the same as the training channel.

e) The chute channel is curved to connect smoothly with the Bengawan Solo River.

f) Width of the channel is set out 15 m from the beginning of training channel to end of the chute channel.

(2) Type of Inlet

A front overflow weir type is adopted as the new spillway inlet to secure effective functioning for sediment flushing.

(3) Gate

Gate size has been determined to accommodate the design discharge from the sediment storage reservoir. A radial gate type has been adopted to reduce the impact caused by sediment releasing.

(4) Type of Energy Dissipater

A ski jump type is adopted as the energy dissipater because of the reasons as listed below.

Bed elevation of the plunge pool is set at EL.100 m applying the same elevation to the plunge pool as the existing spillway.

a) The area along the spillway channel route is underlain by a very stiff layer (hard rock) suitable for foundation. The ski jump type dissipater requires not little excavation. If a hydraulic jump type dissipater is adopted, the excavation volume might be larger than that of ski jump type.

b) Gradient of the chute channel slope is very gentle at 1/108. Therefore, the flow velocity in the channel is not so high. Flow velocity in the chute channel is around 9.7 m³/s when the flow is 400 m³/s.

c) A ski jump dissipater was adopted for the existing spillway.

3.2.2 Design

(1) Inlet of Spillway

Foundation elevation of the inlet is set at EL.127.0 m, the same elevation as the design level of sediment deposits to allow the sediment flushing function. Maximum design discharge is 1,270 m³/s at PMF (water level EL.139.1 m). Design discharge to be released
is 400 m³/s at SHFD with a peak discharge of 4,000 m³/sec.

Width of inlet is required to be more than B=15.0 m to keep the water level, from the overflow weir equation below, under EL.139.1 m at PMF.

In this design, a two gate (B =7.5 m) system is adopted due to maintenance work. Usually, more than two gates are recommended for sediment flushing in terms of maintenance.

\[ Q = CBH^{3/2} \]

where,  
\( C \) : Coefficient of overflow weir \( C=2.0 \)  
\( B \) : Width of inlet (m)  
\( H \) : Water depth at inlet (m) \( 139.1-127.0 = 12.1 \) m  
\( Q \) : Discharge (m³/s)

![Discharge of New Gate (B7.5m×h m×2nos)](image)

![Width-Water Depth Curve](image)

(2) Training Cannel Portion

The training channel crosses the dam axis and runs close to the dam body. A gravity type retaining wall is adopted for the training channel. Typical cross section is shown in Figure
3.2.5. Principal design conditions are set at:
- Slope of back face of the wall is 1:0.7 due to the stability of the wall.
- Slope of training channel is 1/108.
- Design discharge is 1,270 m$^3$/s.
- Water depth at design discharge $h=6.2$ m is given from below Manning formula.
- Free board, $h=0.8$ m is applied.
- Height of wall $H=6.2+0.8=7.0$ m.

Manning formula \[ v = \frac{1}{n} \cdot R^{2/3} \cdot I^{1/2} \]

\[ Q = A \cdot v \]

where,
- $n$: Coefficient of roughness, $n=0.016$ (concrete channel)
- $A$: Flow area ($m^2$)
- $V$: Velocity ($m/s$)
- $Q$: Discharge ($m^3$/s), Design discharge $Q=1,270m^3/s$
- $I$: Gradient 1/108
- $R$: Hydraulic mean depth ($R=S/h$)
- $S$: Total edge length in water ($m$)
- $H$: Water depth ($m$)
- $V$: Velocity ($m/s$), $V=13.6$ $m/s$ at $1,270$ $m^3/s$, $V=9.7m/s$ at $400$ $m^3/s$

![Headrace Channel H-Q](source: JICA Study Team)

(3) Chute Channel Portion

Gradient of the chute channel is $I=1/108$, which is the same with the training channel.

Reinforced concrete walls are adopted for the walls of the chute channel to reduce excavation volume and concrete volume. Typical cross section is shown in Figure 3.2.5. Principal design conditions are set at:
- Slope of chute channel is $I=1/108$.
- Design discharge is $400$ $m^3/s$ at surcharge water level and $1,270m^3/s$ at PMF.
- Water depth at design discharge $h=6.2$ m.
- Free board $h=0.8$ m.
- Height of wall \( H = 6.2 + 0.8 = 7.0 \) m.
- Velocity \( V = 9.7 \) m/s at 400 \( m^3/s \), \( V = 13.6 \) m/s at 1,250 \( m^3/s \).

(4) Energy Dissipater

A ski jump type energy dissipater is adopted for new spillway. Target discharge is 400 \( m^3/s \) at the SHFD. Flow velocity is 9.7 m/s, which is very low due to gentle chute channel gradient of 1/108. Gradient of 1/108 is categorized as a natural river.

a) Features of ski jump bucket for energy dissipater

This type of energy dissipater has an advantage in the construction cost, while the effectiveness as a dissipater is less compared with the normal type, and the flow regime of the plunge pool and downstream river is unstable.

b) Trajectory and extent of the area of falling jet

Trajectory of free-discharging jet is estimated by the following formula:

\[
y = \tan \theta \cdot x - \frac{x^2}{4 \cos \theta^2 \cdot KHo}
\]

where,

\( K \): Coefficient obtained after deducting friction loss and other losses in the channel from 1.0 are as shown below.

\[
\begin{align*}
K &= 0.69 \ (Q=1,000 \ m^3/s) \\
K &= 0.73 \ (Q=1,600 \ m^3/s) \\
K &= 0.65 \ (Q=400 \ m^3/s) \\
K &= 0.71 \ (Q=1,250 \ m^3/s)
\end{align*}
\]

\( K \) values come from the “Report on the Hydraulic Model Test on Revised Spillway of Karangkates Project (1971)”

\( \theta \) : Angle of Jet jumping \( \theta = 30^\circ \)

![Figure 3.2.7 Trajectory of Jet Water](source: JICA Study Team)
Table 3.2.1 Trajectory of Jet Water

<table>
<thead>
<tr>
<th>Water Level of Reservoir</th>
<th>Water Level of River</th>
<th>Difference $\Delta h$(m)</th>
<th>$X_{max}$ (m)</th>
<th>$Y_{max}$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL.138.3m</td>
<td>EL.106.0m</td>
<td>32.3</td>
<td>52.0</td>
<td>5.19</td>
</tr>
<tr>
<td>EL.139.1m</td>
<td>EL.106.0m</td>
<td>33.1</td>
<td>53.0</td>
<td>5.34</td>
</tr>
</tbody>
</table>

Source: JICA Study Team

(5) Quantities

Quantities for the closure dike are shown in Table 4.2.2.

Table 3.2.2 Main Quantity of New Spillway

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Spillway</td>
<td>m</td>
<td>708.79</td>
</tr>
<tr>
<td>Training Channel</td>
<td>m</td>
<td>162.55</td>
</tr>
<tr>
<td>Chute Channel</td>
<td>m</td>
<td>452.24</td>
</tr>
<tr>
<td>Energy dissipater</td>
<td>m</td>
<td>94</td>
</tr>
<tr>
<td>Width of Spillway</td>
<td>m</td>
<td>15.00</td>
</tr>
<tr>
<td>Concrete Volume</td>
<td>m$^3$</td>
<td>93,320</td>
</tr>
<tr>
<td>Excavation</td>
<td>m$^3$</td>
<td>389,240</td>
</tr>
<tr>
<td>Backfill</td>
<td>m$^3$</td>
<td>134,970</td>
</tr>
</tbody>
</table>

Source: JICA Study Team

Figure 3.2.8 Trajectory of Falling Jet Water
3.3 Closure Dike

(1) Design Conditions and Criteria

Purpose of the closure dike is to separate the sediment storage reservoir from the Wonogiri main reservoir up to the surcharge water level. However, when the water level is over the surcharge water level, the closure dike is designed to be submerged. A closure dike should be safe from sudden lowering of water level from EL. 136.0 m (normal water level) to EL. 127.0 m (designed sediment deposits level).

Therefore, design condition and criteria shall be as follows,

- Height of Closure Dike : EL.138.3 m (Surcharge water level)
- Free Board : $\Delta h = 0$ m
- Foundation height : EL.127.0 m
- Face Slope of Dike : 1:3.0

(2) Layout Plan

The closure dike is planned to run from the right abutment of the Wonogiri dam to the top edge of the peninsula that is located in front of the dam. Another purpose of the closure dike is to prevent sediment inflow from the Keduang River from flowing into the intake directly and to reduce garbage gathering at in front of the intake.

Layout plan of the closure dike is shown in Figure 3.3.1.

(3) Type of the Closure Dike

The earth-fill cofferdam type is selected for the closure dike for economic reasons and to secure the sand spoil bank resulting from the spillway excavation. However, there will be overflow over the closure dike during floods, from the water level of the Design flood (EL.138.3 m) to the PMF (EL.139.1 m). There might be the possibility of scouring at the foot and face of the closure dike during sediment flushing. Therefore, a double-wall constructed from steel sheet piles with a penetration depth reaching the original ground, is designed to be incorporated at the top of the closure dike. Width of the closure dike is 10 m, which is determined by stability analysis of the double-sheet pile wall.

Face slope of the dike is adopted at 1:3.0 to secure the safety of slope from failure with the rapid lowering of water level from 136 m to 127 m in one day.

Typical cross section of the closure dike is shown in Figure 3.3.1.

(4) Quantities

Quantities for the closure dike are shown in Table 3.3.1.

Table 3.3.1 Main Quantity of Closure Dike

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of dike</td>
<td>m</td>
<td>658.00</td>
</tr>
<tr>
<td>Height of dike</td>
<td>m</td>
<td>Top of dike</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EL.138.3 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Foundation height</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EL.127.0 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$H_{\text{max}} = 11.3$ m</td>
</tr>
<tr>
<td>Embankment volume</td>
<td>m$^3$</td>
<td>167,800</td>
</tr>
<tr>
<td>Steel sheet pile</td>
<td>t</td>
<td>4,450</td>
</tr>
</tbody>
</table>

Source: JICA Study Team
3.4 Overflow Dike

(1) Design Condition and Criteria

The overflow dike is designed to transfer water from the sediment storage reservoir to the main reservoir, and vice versa when the reservoir water level is over EL. 136.0 m (normal water level) in the main reservoir. Length of the overflow dike was determined by the flood routing calculation. Plan and typical cross section are shown in Figure 3.4.1. Conditions and criteria are as follows:

- Crest height of overflow dike EL.136.0 m
- Difference in height between the crest and apron is 2.0 m from topographical and geological conditions
- Design discharge Q=550 m³/s (at water lever EL.138.1 m in the sediment storage reservoir and EL.137.8 m in the main reservoir)
- Direction of flow is both sides

![Overflow Dike B=250m Discharge-water depth Curve](image)

Source: JICA Study Team

Figure 3.4.2 H-Q Curve of Overflow Dike

(2) Layout Plan

Overflow dike is planned to be on the peninsula lying from the opposite shore of the Wonogiri dam. The location of the overflow dike is selected on ridge of peninsula due to geological conditions. Both sides of the overflow dike are embanked up to EL.138.3 m and connected to the closure dike and the shore opposite the dam.

In the overflow dike, a connecting conduit (2.0 m × 2.0 m) with a gate is installed to transfer water in the sediment storage reservoir between EL. 136.0 m and 132.0 m to the main reservoir in the dry season. Width of the dike is about 250 m to satisfy the required function. Plan and section of connecting conduit is shown in Figure 3.4.3.

(3) Type of Overflow Dike

A concrete fixed weir type is adopted for the overflow dike because it is maintenance free.

Direction of flow on the dike is considered reversible. Therefore, the layout needs to have apron works on both sides. Distance between both weirs is set at 10 m to secure
maintenance and allow an access road.

(4) Quantities

Quantities for the overflow dike are shown in Table 3.4.1

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the dike</td>
<td>m</td>
<td>250.00</td>
</tr>
<tr>
<td>Height of dike</td>
<td>m</td>
<td>Crest height EL.136.0 m, Apron EL.134.0 m</td>
</tr>
<tr>
<td>Excavation</td>
<td>m³</td>
<td>29,750</td>
</tr>
<tr>
<td>Concrete</td>
<td>m³</td>
<td>11,000</td>
</tr>
<tr>
<td>Earth filling</td>
<td>m³</td>
<td>61,600</td>
</tr>
</tbody>
</table>

Table 3.4.1 Main Quantity of Overflow Dike

Source: JICA Study Team
Figure
Attachment 1

Quantity Calculation
(New Spillway)
<table>
<thead>
<tr>
<th>No. Station</th>
<th>Distance</th>
<th>Acc. Distance</th>
<th>Area</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(m)</td>
<td>(m)</td>
<td>Excavation</td>
<td>Concrete</td>
</tr>
<tr>
<td>P.0</td>
<td>0</td>
<td>0</td>
<td>333.34</td>
<td>56.90</td>
</tr>
<tr>
<td>P.0+14.79</td>
<td>14.79</td>
<td>14.79</td>
<td>366.04</td>
<td>56.90</td>
</tr>
<tr>
<td>P.1</td>
<td>50</td>
<td>64.79</td>
<td>342.22</td>
<td>56.66</td>
</tr>
<tr>
<td>P.2</td>
<td>50</td>
<td>114.79</td>
<td>359.26</td>
<td>56.31</td>
</tr>
<tr>
<td>P.3</td>
<td>50</td>
<td>164.79</td>
<td>353.59</td>
<td>55.93</td>
</tr>
<tr>
<td>P.4</td>
<td>50</td>
<td>214.79</td>
<td>348.96</td>
<td>55.58</td>
</tr>
<tr>
<td>P.5</td>
<td>50</td>
<td>264.79</td>
<td>387.90</td>
<td>55.23</td>
</tr>
<tr>
<td>P.6</td>
<td>50</td>
<td>314.79</td>
<td>409.78</td>
<td>54.88</td>
</tr>
<tr>
<td>P.7</td>
<td>50</td>
<td>364.79</td>
<td>606.80</td>
<td>144.67</td>
</tr>
<tr>
<td>P.8</td>
<td>50</td>
<td>414.79</td>
<td>746.64</td>
<td>209.31</td>
</tr>
<tr>
<td>P.9</td>
<td>50</td>
<td>464.79</td>
<td>1,123.85</td>
<td>288.47</td>
</tr>
<tr>
<td>P.10</td>
<td>50</td>
<td>514.79</td>
<td>1,204.21</td>
<td>352.40</td>
</tr>
<tr>
<td>P.11</td>
<td>50</td>
<td>564.79</td>
<td>1,077.14</td>
<td>325.87</td>
</tr>
<tr>
<td>P.12</td>
<td>50</td>
<td>614.79</td>
<td>1,010.31</td>
<td>320.70</td>
</tr>
<tr>
<td>Total</td>
<td>614.79</td>
<td></td>
<td>387,598.17</td>
<td>134,608.35</td>
</tr>
</tbody>
</table>
LONGITUDINAL PROFILE DAM CREST

LONGITUDINAL PROFILE OF NEW SPILLWAY

FIGURE
PROFILE OF NEW SPILLWAY
<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>0.00</th>
<th>10.00</th>
<th>20.00</th>
<th>30.00</th>
<th>40.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation</td>
<td>140</td>
<td>136</td>
<td>134</td>
<td>132</td>
<td>130</td>
</tr>
<tr>
<td>P.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Original Ground</td>
<td>140</td>
<td>136</td>
<td>134</td>
<td>132</td>
<td>130</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>0.00</td>
<td>10.00</td>
<td>20.00</td>
<td>30.00</td>
<td>40.00</td>
</tr>
<tr>
<td>Elevation</td>
<td>140</td>
<td>136</td>
<td>134</td>
<td>132</td>
<td>130</td>
</tr>
<tr>
<td>P.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Original Ground</td>
<td>140</td>
<td>136</td>
<td>134</td>
<td>132</td>
<td>130</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>0.00</td>
<td>10.00</td>
<td>20.00</td>
<td>30.00</td>
<td>40.00</td>
</tr>
<tr>
<td>Elevation</td>
<td>140</td>
<td>136</td>
<td>134</td>
<td>132</td>
<td>130</td>
</tr>
<tr>
<td>P.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Original Ground</td>
<td>140</td>
<td>136</td>
<td>134</td>
<td>132</td>
<td>130</td>
</tr>
</tbody>
</table>

Excavation = 358.65 m³
Embankment (Backfill) = 75.70 m³

Excavation = 362.59 m³
Embankment (Backfill) = 75.70 m³

Excavation = 347.65 m³
Embankment (Backfill) = 75.70 m³

CROSS SECTION SPILLWAY
Excavation Area = 1,246.700 m²
Embankment Area = 24.630 m²
Concrete Area = 131.840 m²

EL+100.000

P.5

Excavation Area = 1,472.580 m²
Concrete Area = 131.840 m²

EL+100.000

P.6

CROSS SECTION OF DISSIPATER