Annex No.5
Verification Test for Hydro-Suction System for Sediment Removal

THE STUDY ON
COUNTERMEASURES FOR SEDIMENTATION
IN
THE WONOGIRI MULTIPURPOSE DAM RESERVOIR
IN
THE REPUBLIC OF INDONESIA

FINAL REPORT

SUPPORTING REPORT I

Annex No.5: Verification Test for Hydro-Suction System for Sediment Removal

Table of Contents

Page

List of Tables

List of Figures

Attachment

CHAPTER 1 INTRODUCTION

1.1 Background of Verification Test

The sedimentation problem on the intake of Wonogiri Reservoir is regard as the one that needs to be urgently solved in case its inlet portion is likely to be filled up with sediments, since it has adverse effects on hydropower generation and irrigation water supply to the downstream areas.

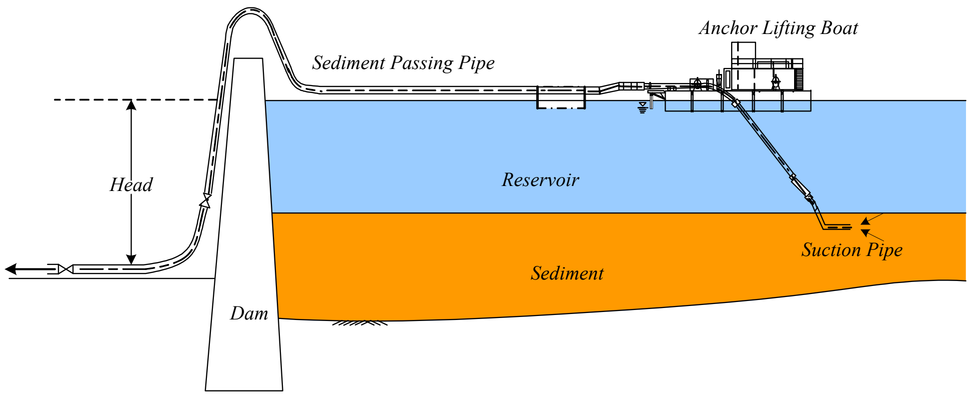
Conventional hydraulic dredging has been commonly used to remove sediments in reservoirs in the world because of its reliability. But nowadays there is a tendency not to accept this way owing to the following reasons.

i) Hydraulic dredging is relatively high in cost.

ii) Acquisition of sufficient spoil bank for disposal of dredged material is quite difficult.

iii) Request to release sediments from reservoir has been increasing among the people considering of river environment.

Hydro-suction System is much note for the new sediment extractor on above-mentioned subjects in Japan. To remove sediments from reservoir, it utilizes a head between reservoir water surface and outlet point, which is located downstream of dam as illustrated below:



Source: JICA Study Team

Figure 1.1.1 Schematic Profile of Hydro-Suction System

This is also useful to remove sediments at around the intake of Wonogiri Reservoir to keep the function with the maintenance-free and sustainable condition.

On the other hand, technologies on Hydro-suction System are still under development and operation of the new system has not yet been practiced in existing reservoir as the permanent measure in Japan. In addition, there are some uncertain matters in applying to Wonogiri Reservoir in this stage. One of them is that a large quantity of vegetative debris and garbage are washed to the front of the intake after flood and most of them finally accumulate on the reservoir bed. Therefore, the new system requires a verification test to certify whether it is effectively applicable to remove the sediments composed of consolidated silt, sand, clay mixed with vegetative debris and garbage in Wonogiri Reservoir. Taking such aspects into consideration, it was determined that the countermeasure for sediment accumulation at and around the intake be selected based on the results of Verification Test in the field.

1.2 Objective of Verification Test

The objectives of Verification Test are as follows:

i) To confirm whether Hydro-suction System is applicable to the sediment materials containing vegetative debris and garbage in Wonogiri Reservoir

ii) To collect and analyze the basic operational data related to Hydro-suction System

iii) To examine and develop Hydro-suction System, which can be operated at low cost through energy saving

CHAPTER 2 OVERVIEW OF VERIFICATION TEST

2.1 Schedule of Verification Test

Verification Test was carried out at the field in Wonogiri Reservoir, being conducted by entrusting it to a qualified Japanese sub-contractor, Damdre Co., Ltd., for the period from September 12th to October 31st, 2005. The detailed schedule of the verification test is shown in Table 2.1.1 below.

Table 2.1.1 Schedule of Verification Test

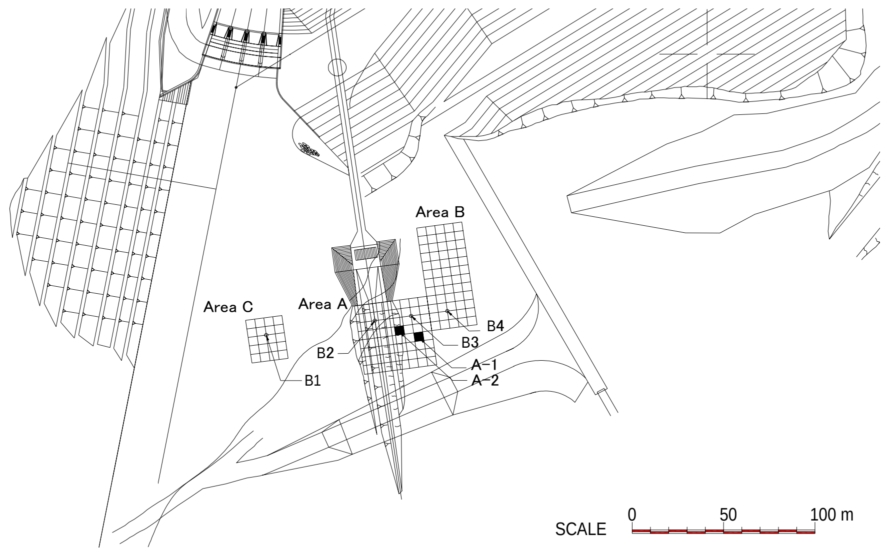
Work Item	Aug.	Sep.	Oct.	Nov.	Dec.
Planning and Designing of Test	....	....			
Production and Mobilization		▬			
Transportation and Installation		▬	▬		
Pre-test.		▬	▬		
Final Test			▬	▬	
Demobilization			▬	▬	
Evaluation and Reporting				....	....

...... Work in Japan
▬ Work in Indonesia

As shown in the table above, the verification test was conducted in two (2) stages, namely pre-test and final test. The pre-test aimed to preliminarily confirm the functions of all equipment and devices for the hydro-suction system and to establish the applicable system for the final test. After the pre-test, the final test was conducted to collect the detail operational data using the applicable system.

2.2 Location of Verification Test

Locations of Verification Test were selected at and around the intake as shown in Figure 2.2.1 below. The pre-test and final test were carried out at A-1 and A-2 points, respectively, which are shown in Figure 2.2.1.



Source: JICA Study Team

Figure 2.2.1 Location of Verification Test

2.3 Selection of Hydro-suction System Type

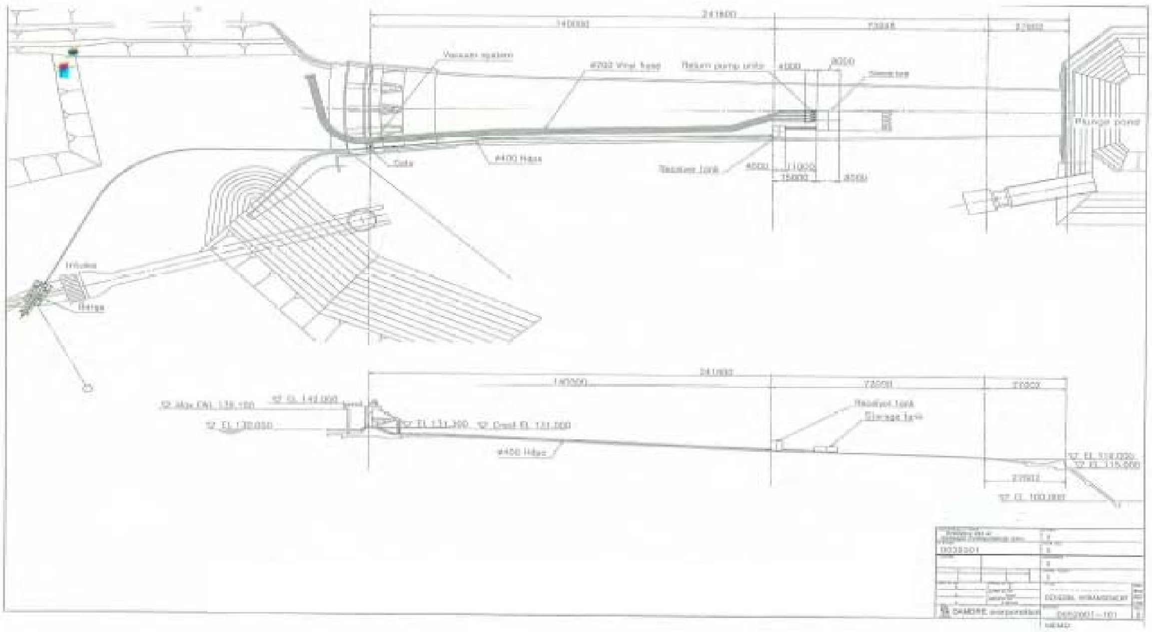
The hydro-suction system is roughly classified into two (2) types, namely mobile type and fixed type. In case of the fixed type, a dredging area is limited on account of a discharge pipe being embedded at reservoir bottom, while a dredging area of the mobile type is not limited owing to being able to move to any position in reservoir. In addition to this, the fixed type has a weakness for garbage for its rigidity. Consequently, the mobile type was selected for the verification test in Wonogiri Reservoir.

2.4 Equipment of Verification Test

Equipment for Verification Test was mainly composed of Barge, Discharge Pipe (Φ 400mm, High-density polyethylene), Receiving Tank (L4.0m x W5.0m x H4.0m), Storage Tank (L8.0m x W9.0m x H2.0m) and Return-to-Reservoir Pipe (including pump).

The Plane figure of the equipment is shown in Figure 2.4.1. And photos of those equipment were shown in Photo 2.4.1 to 2.4.5.

Receiving Tank, Storage Tank and Return-to-Reservoir Pipe are normally not necessary for the hydro-suction system. Those were added as countermeasure to prevent discharge flow (including sediment material) going downstream in consideration of river environment in this test.



Source: JICA Study Team

Figure 2.4.1 Plane of Hydro-suction System

Photo 2.4.1 Barge and Discharge Pipe

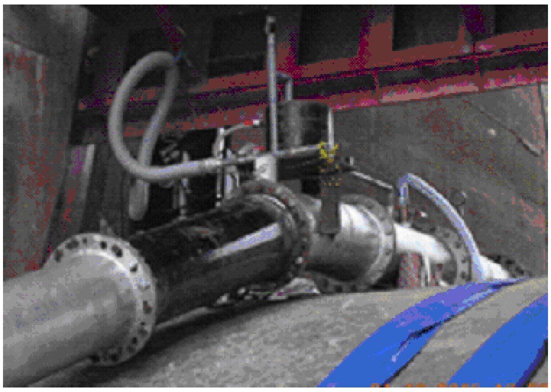


Photo 2.4.2 Discharge Pipe over Crest at Spillway

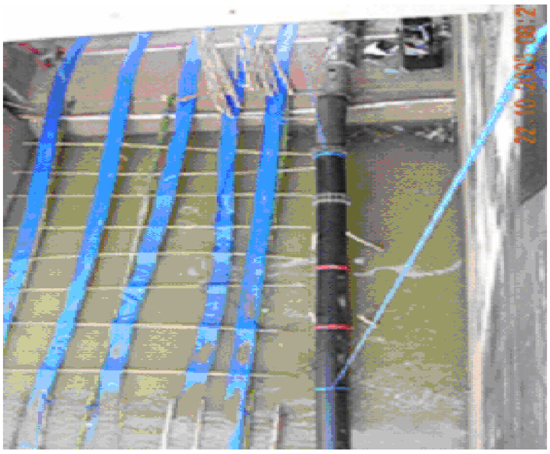


Photo 2.4.3 Return-to-Reservoir Pipe

Photo 2.4.4 Receiving Tank

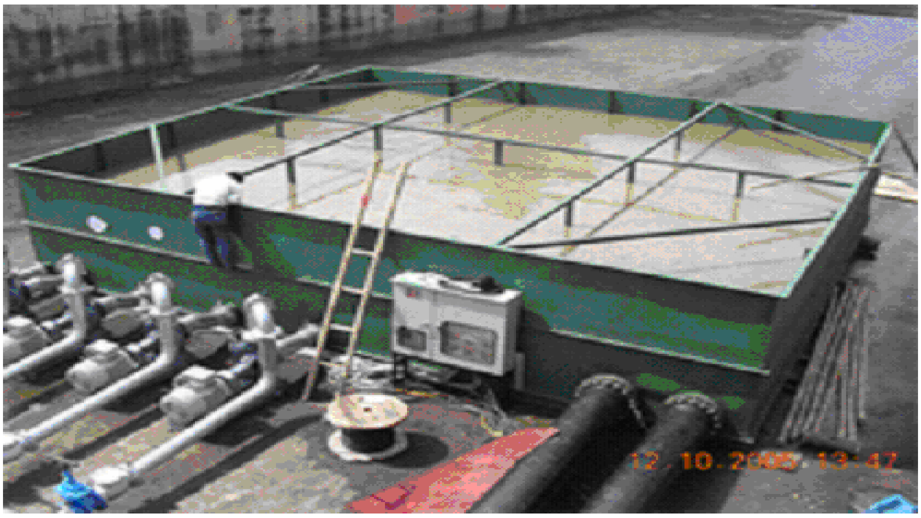


Photo 2.4.5 Storage Tank

Source: JICA Study Team

2.5 Method of Verification Test

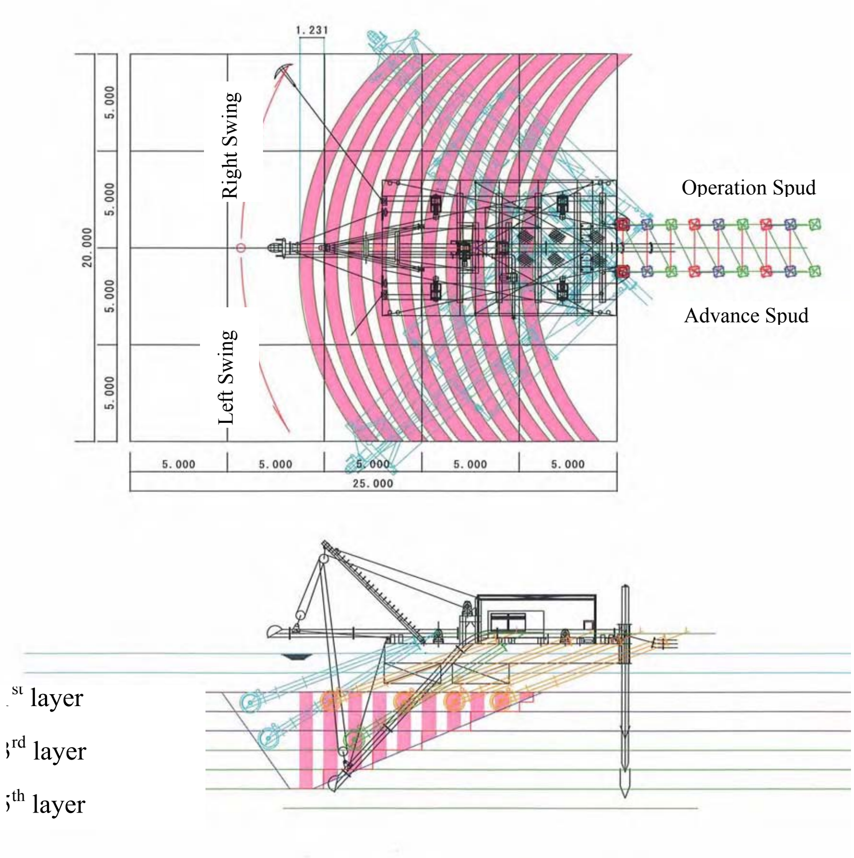
Verification Test was carried out following order.

(1) Preliminary Works

Before beginning the hydro-suction system operation, the discharge pipe was filled up with water to cause the siphon phenomenon by using water pump and vacuum pump.

(2) Dredging

In succession to the above preliminary works, it was ensured that the discharge pipe on the barge could move up- and downwards and to the left and right by winch and that the barge could move back and forward using the side winches for an anchor at gunwale and spuds. The dredging area and depth was controlled by handling these equipment as shown Figure 2.5.1 below.



Source: JICA Study Team

Figure 2.5.1 Mode of Dredging

(3) Piping

The discharge pipe was extended into the downstream direction from the barge getting over crest at the spillway. A high-density polyethylene pipe of 400mm in diameter was used for the main pipeline.

(4) Releasing

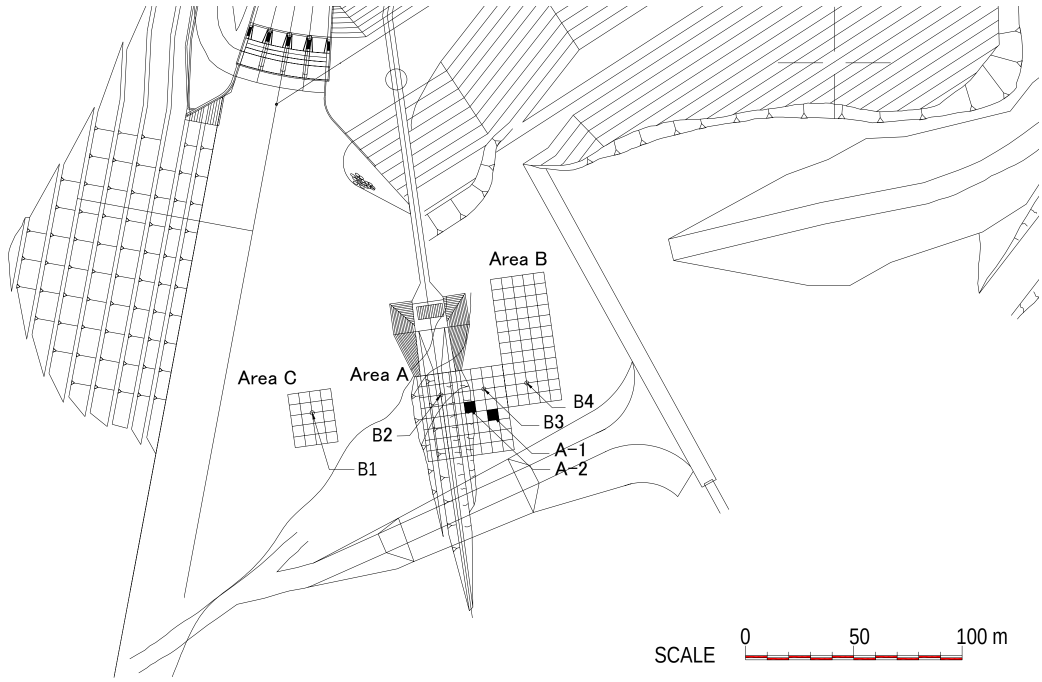
In consideration of the environmental aspect, discharge water used for the dredging was released into the storage tank through the receiving tank, those were placed on the middle portion of the spillway, in order to prevent it from flowing down. Subsequently, discharge water in the storage tank was returned into the reservoir by operating the return pumps.

CHAPTER 3 GEOTECHNICAL CONDITION OF SEDIMENT IN WONOGIRI RESERVOIR

Geotechnical conditions of sediments deposited at and around the intake in Wonogiri Reservoir were examined by the core drilling and the soil mechanical test.

3.1 Location of Core Drilling

The core drilling was carried out at B-1 to B-4 points to a depth of 5.5m. The location of the core drilling is shown in Figure 3.1.1.



Source: JICA Study Team

Figure 3.1.1 Location of Core Drilling

3.2 Results of Soil Mechanical Test

The soil mechanical test was conducted to clarify the grain size distribution, specific gravity and density of the sediments. The results of the soil mechanical test are shown in Table 3.2.1 below.

The sediments deposited at and around the intake consist of clay, silt, sandy clayey silt, and sandy silt. The specific gravity values of the soil particles at the locations are almost in the range of 2.6 to 2.7. A void ratio of the surface layer (0-1m in depth) is 60% or higher, becoming smaller with depth. Accordingly, there is a tendency that the sediments in Wonogiri Reservoir are consolidated in the deeper portion.

Table 3.2.1 Results of Soil Mechanical Test

Point	B-1			B-2			B-3			B-4		
Depth (m)	Soil	Specific gravity	Void ratio (%)	Soil	Specific gravity	Void ratio (%)	Soil	Specific gravity	Porosity (%)	Soil	Specific gravity	Void ratio (%)
0.0 – 0.5	Clay silt	2.658	63.63	Clay silt	2.690	60.92	Clay	2.616	61.47	Silty clay	2.604	60.36
1.0 – 1.5	Sandy clayey silt	2.620	62.55	Clay	2.640	57.84	Sandy silt	2.653	56.13	Clay	2.619	59.83
2.0 – 2.5	Sandy clayey silt	2.597	61.69	Clay	2.589	52.29	Sandy silt	2.692	56.32	Clay	2.681	60.81
3.0 – 3.5	Sandy clayey silt	2.610	59.67	Sandy clayey silt	2.706	55.98	Silt	2.588	56.53	Sandy clayey silt	2.652	57.47
4.0 – 4.5	Sandy silt	2.661	59.59	Clay	2.655	54.72	Sandy clayey silt	2.587	59.00	Sandy clayey silt	2.634	55.46
5.0 – 5.5	Sandy silt	2.620	53.12	Clay	2.590	53.32	Clay	2.600	52.26	Sandy clayey silt	2.616	53.32

Note: The void ratio (P) is calculated by following equation.

$P = (1 - \gamma d/\gamma s) \times 100$ (%)

γd : Specific gravity in dry condition (g/cm^3)

γs : Specific gravity of soil particle (g/cm^3)

Source: JICA Study Team

CHAPTER 4 VERIFICATION TEST

4.1 Pre-Test

4.1.1 Purpose

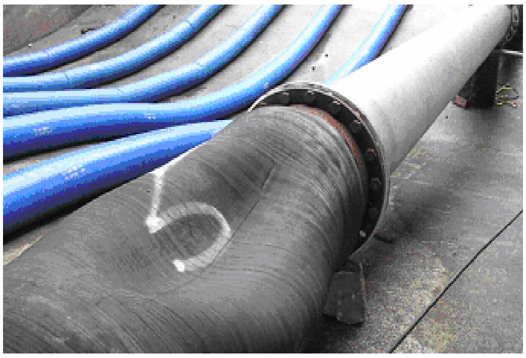
Pre-test was carried out to check the functions of all equipment and to select the best excavator for the final test.

4.1.2 Remarks on Pre-Test

(1) Flow Velocity

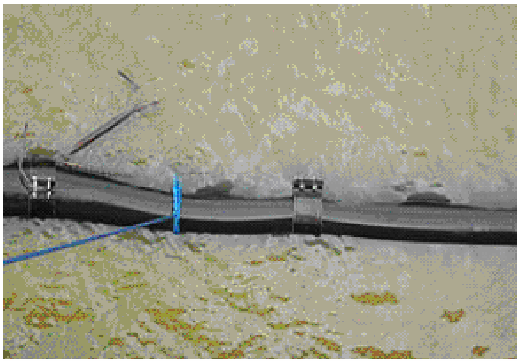
The maximum flow velocity of 2.2 m/s and flow rate of 16.6 m^3/mim. assumed in calculations, were not confirmed due to occurring a trouble of the flexible hose and the high density polyethylene pipe, even though flow velocity of 1.9 m/s and flow rate of 14.5 m^3/min. were secured. (shown in Photo 4.1.1 to 4.1.2)

Based on the above-mentioned situation, operation with a pipe internal pressure of less than -2.4 m was judged to be impossible, and the subsequent tests were carried out by operating the system with an internal pressure of -2.4 m or more.



Source: JICA Study Team

Photo 4.1.1 Deformation of the Rubber Flexible Jjoint



Source: JICA Study Team

Photo 4.1.2 Deformation of the High Density Polyethylene

(2) Excavator

The excavator used for the pre-test were the water jet nozzle and the side rotary type. (Shown in Photo 4.1.3 to 4.1.4 and Figure 4.1.1 to 4.1.2 respectively)

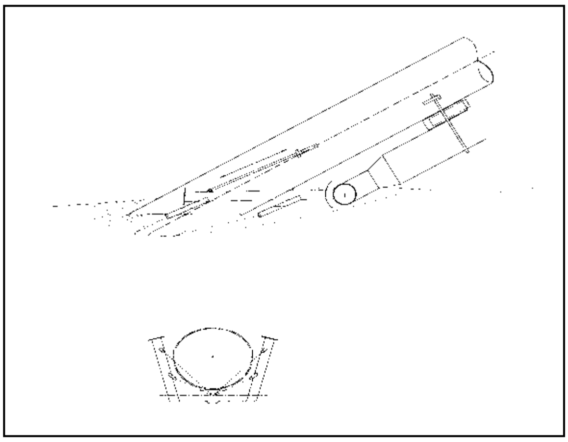
Table 4.1.1 shows the flow rate of the flow velocity in the pipe, density, volumetric concentration, amount of discharged sediments, amount of discharged sediments per unit of time, power consumption, and amount of discharged sediment per unit of power in each operation. A total evaluation of each of the excavator based on the above was made with the results shown in Table 4.1.2. In consideration of the evaluation, the side rotary excavator was selected for the final test.

Source: JICA Study Team

Photo 4.1.3 Water Jet Nozzle

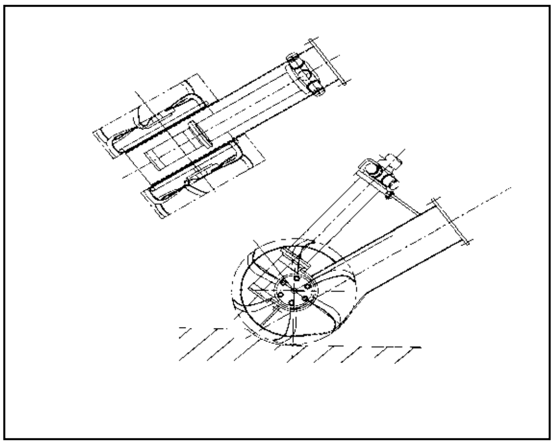
Source: JICA Study Team

Photo 4.1.4 Side Rotary Type



Source: JICA Study Team

Figure 4.1.1 Water jet nozzle



Source: JICA Study Team

Figure4.1.2 Side rotary type

Table 4.1.1 Results of Pre-test

Excavator	Flow rate	Velo-city	Density	Concen-tration	Pipe length	Dredging volume	Dredgingvolume per unit time	Electricity consump-tion	Dredgin volume per unit electric power	Water consump-tion	Water consump-tion per unit dredging volume
	m^3/min.	m/s	g/cm^3	%	m	m^3	m^3/hr	kwh	m^3/kwh	m^3	m^3/$m^{3/}$
Water jet nozzle	8～14.3	1.1～1.9	1.027～1.053	4.72～9.27	360	3.8	11.5	11	0.3	206.0	54.2
Side rotary	8～10.5	1.1～1.4	1.025～1.058	3.66～8.48	360	8.1	24.5	1	8.1	181.5	22.4
Side rotary (No power)	9～13.4	1.2～1.8	1.027～1.048	3.95～7.02	360	4.9	14.8	0	－	217.9	44.5

Note : Absolute volumetric concentration C(%) = (γ−1)／(γ s −1) ×100
Volumetric concentration C’(%) = C／(1−P／100)
where; γ: density in pipe (g/cm^3) γ s :specific gravity for soil particle P :soil prosity(%)
Source: JICA Study Team

Table 4.1.2 Evaluation of Each Excavator

Excavator	Amount of discharged sediment per unit of time (m^3/h)	Amount of discharged sediment per unit of power (m^3/kwh)	Water consumption per unit of discharged sediment (m^3/m^3)	Blockage by garbage
Jet nozzle	3	3	3	1
Side rotary	1	2	1	2
Side rotary without power	2	1	2	2

Note; 1 ranks above 2 and 3.
Source: JICA Study Team

(3) Evaluation of Pipe

Though deformation occurred in the discharge pipe made of high density polyethylene and rubber flexible joint due to negative pressure, this problem would be dissolved by using high density polyethylene pipe and rubber flexible joint, which have higher strength. The high density polyethylene pipe is considered to be more adequate for the discharge pipe, owing to its lightweight, excellent workability, wear resistance, durability, and low head loss in comparison with steel pipe.

4.2 Final Test

4.2.1 Conditions

The final test using side rotary excavator was carried out for the sixteen (16) different conditions worked out by changing depth and flow rate as shown in Table 4.2.1.

Table 4.2.1 Conditions of Verification Test

Excavator	Side rotary		
Flow rate (m^3/min)	9.5,9.9,10.0,10.3,10.9, 11.0	10.3,11.0,11.8,12.0, 12.5	11.3,11.5,11.6,11.7, 12.0
Depth of excavation	1 m	2 m	3 m
Number of Conditions	6	5	5

Source: JICA Study Team

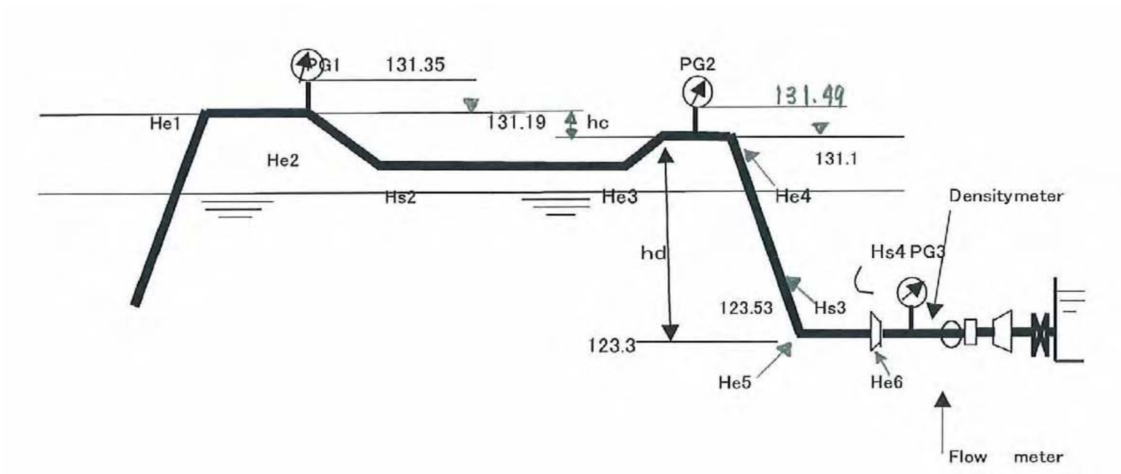
4.2.2 Head Loss

(1) Clear Water Operation

The head loss in the pipeline was derived from the actually measured values with pressure gauges, PG1, PG2, PG3 (See Figure 4.2.1) for the flow rate, which was adjusted by the valve opening. The following "Darcy-Weisbach" formula was used to calculate the head loss:

$$H = \lambda \cdot \frac{v^2}{2g} \times \frac{L}{D}$$

where H: Head loss(m)
λ: Pipeline friction coefficient
L: Pipe length (m)
D: Pipe diameter(m)



Source: JICA Study Team

Figure 4.2.1 Piping System

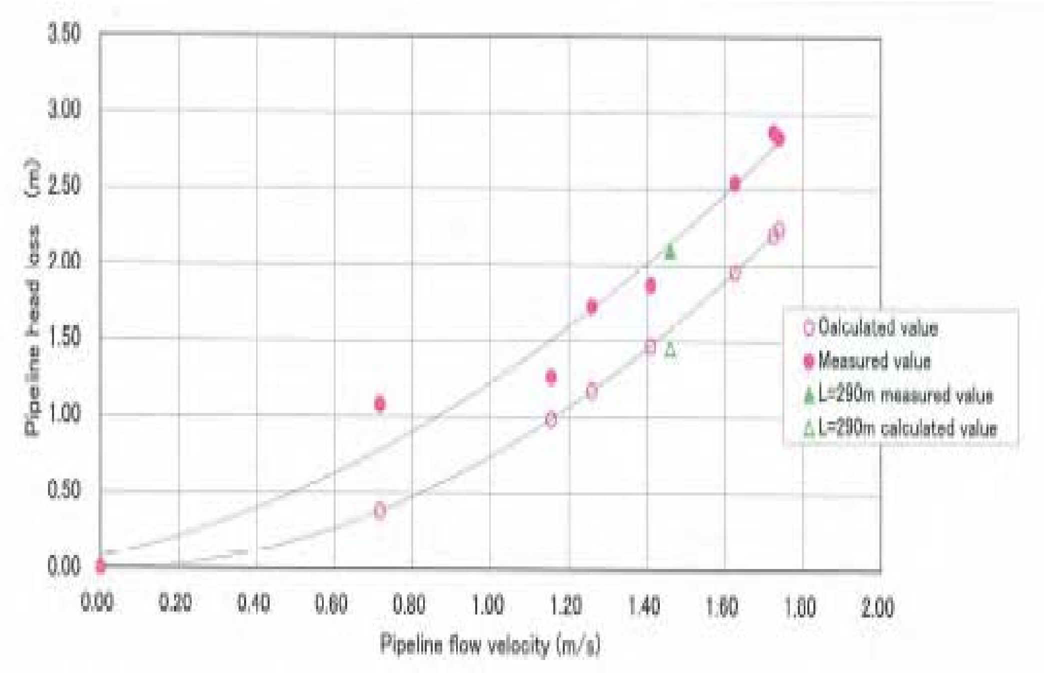
A relationship between velocity and head loss is derived for each of their measured and calculated values as shown in Table 4.2.2 and Figure 4.2.2. In the calculation, a value of 0.018 is adopted as the pipeline friction coefficient. The measured values of head losses become bigger than the calculated ones. Figure 4.2.3 shows a relation between the pipeline length and head loss. Except for the case where the flow velocity is small, the

Table 4.2.2 Pipeline Head Loss

						(Pipe Length = 297.4m)			
Flow Rate	(m^3/min.)	10.63	12.26	13.11	9.49	13.00	5.40	8.71	11.00
Flow Velocity in Pipeline	(m/s)	1.41	1.63	1.74	1.26	1.73	0.72	1.16	1.46
Density	(g/cm^3)	1	1	1	1	1	1	1	1
Actual measured value of the pressure gauge on Barge (PG1: after correction of gauge height)	(m)	-1.14	-1.14	-1.11	-1.08	-1.07	-1.07	-1.07	-1.14
Actual measured value of the pressure gauge on Gate (PG2: after correction of gauge height)	(m)	-1.90	-2.07	-2.24	-1.73	-2.24	-1.06	-1.90	-1.57
Actual measured value of the pressure gauge in front of Receiving Tank (PG3: after correction of gauge height)	(m)	4.88	4.21	3.94	5.08	3.94	6.30	5.56	4.65
Head loss betwewen pressure gauge PG1 and PG2	Hs2(m)	0.7399	0.9841	1.1256	0.5898	1.1068	0.1910	0.4965	0.6770
Bend pipe head loss on Barge : bended angle (30° + 15°) 2 spots	He2(m)	0.0096	0.0128	0.0147	0.0077	0.0144	0.0025	0.0065	0.0103
Bend pipe head loss on Gate : bended angle 15°	He3(m)	0.0022	0.0030	0.0034	0.0018	0.0033	0.0006	0.0015	0.0024
Head between the center of the gate pipe and the center of the pipe at Receiving Tank	hc(m)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Head loss betwewen Barge and Gate (caluculated value)	(m)	0.75	1.00	1.14	0.60	1.12	0.19	0.50	0.69
Head loss betwewen Barge and Gate (measured value)	(m)	0.85	1.02	1.22	0.74	1.26	0.08	0.92	0.52
Head loss between Gate and reducer : HDPE pipe	Hs3(m)	0.3471	0.4617	0.5281	0.2767	0.5192	0.0896	0.2329	0.3718
: steel pipe	(m)	0.3326	0.4424	0.5060	0.2651	0.4975	0.0858	0.2232	0.3554
Bend pipe head loss on Gate : bended angle 15°	He4(m)	0.0022	0.0030	0.0034	0.0018	0.0033	0.0008	0.0015	0.0024
Bend pipe head loss on Gate : bended angle 30°	He5(m)	0.0074	0.0099	0.0113	0.0059	0.0111	0.0019	0.0050	0.0079
Reducer head loss	He6(m)	0.0053	0.0070	0.0080	0.0042	0.0079	0.0014	0.0035	0.0058
Head loss of φ300 pipe	Hs4(m)	0.0254	0.0337	0.0388	0.0202	0.0380	0.0065	0.0170	0.0271
Head between the center of the gate pipe and the center of the pipe at Receiving Tank	hd(m)	7.80	7.80	7.80	7.80	7.80	7.80	7.80	7.80
Head loss between Barge and Gate (calculated value)	(m)	0.72	0.96	1.10	0.57	1.08	0.19	0.48	0.77
Head loss between Barge and Gate (measured value)	(m)	1.02	1.52	1.62	0.99	1.62	0.44	0.34	1.58
Head loss in pipeline (caluculated value)	(m)	1.47	1.96	2.24	1.17	2.20	0.38	0.99	1.46
Head loss in pipeline (measured value)	(m)	1.87	2.54	2.84	1.73	2.88	0.52	1.26	2.10

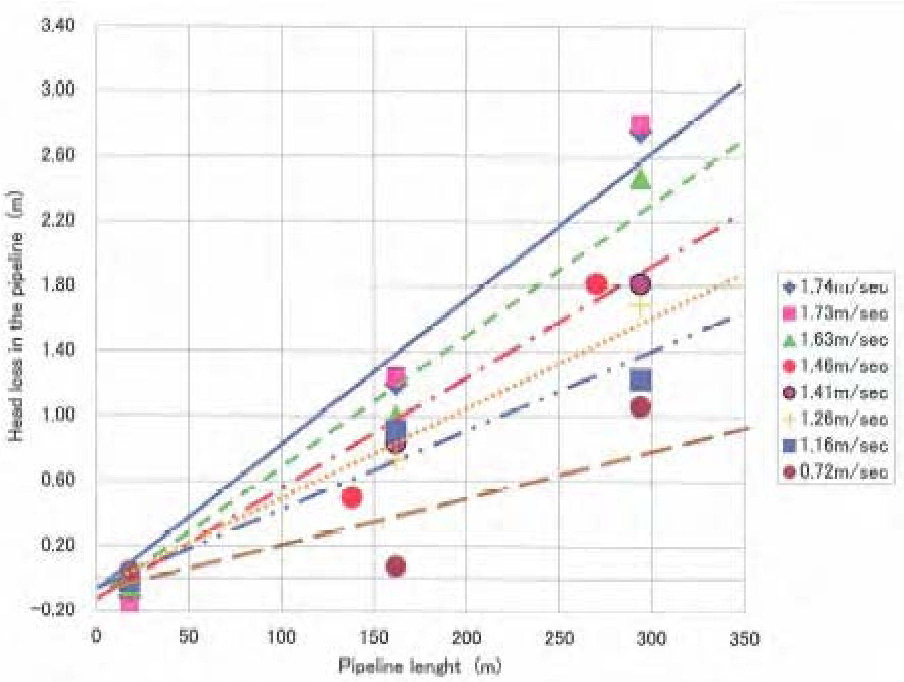
Source; JICA Study Team

relationship is almost linear. The pipeline friction loss coefficient of the high density polyethylene pipe is derived to be 0.0258 on average from the measurement as shown in Table 4.2.3. Since there were flange connections at 6 points and plastic welding at 11 points on the pipeline, it is considered that the derived higher friction loss coefficient is reasonable.



Source: JICA Study Team

Figure 4.2.2 Relation between Velocity and Head loss (Clear Water)



Source: JICA Study Team

Figure 4.2.3 Relation between Pipeline Length and Head Loss (Clear Water)

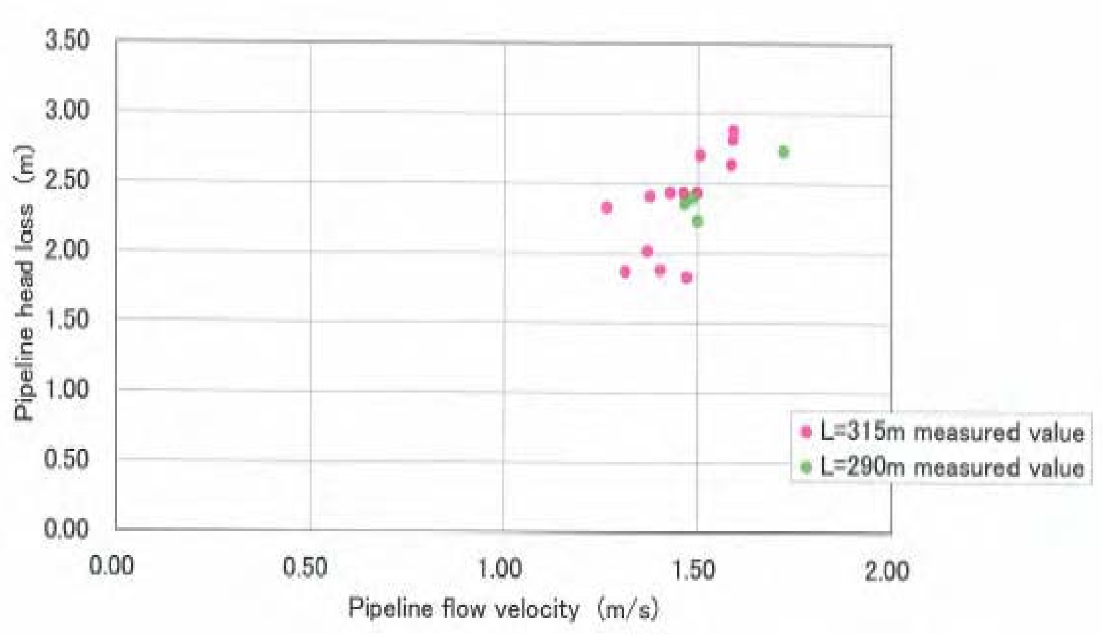
Table 4.2.3 Pipeline Friction Coefficient of High-Density Polyethylene Pipe

Pipeline flow velocity (m/s)		1.41	1.63	1.74	1.26	1.73	0.72	1.16	1.46	Ave.
Calculated value	Φ400mm pipeline head loss (m)	1.09	1.45	1.65	0.87	1.63	0.28	0.73	1.05	
	Pipeline friction coefficient λ	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	
Measured value	Φ400mm pipeline head loss (m)	1.49	2.03	2.25	1.42	2.30	0.42	1.01	1.69	
	Pipeline friction coefficient λ	0.0246	0.0253	0.0245	0.0296	0.0255	0.0272	0.0243	0.0249	0.0258

Source: JICA Study Team

(2) Dredging Operation

The measured values of pipeline head loss during the dredging operation are shown in Figure 4.2.4.



Source: JICA Study Team

Figure 4.2.4 Pipeline (Φ400mm) Head Loss During Dredging

Assuming that the pipeline friction loss factor λ' in case of mud-flow passing through the pipeline is α times of the factor λ in case of clear water, the following equation is derived:

$$\lambda' = \alpha \times \lambda$$

The following equation is generally used to obtain α.[1]

$$\alpha = 1 + \beta \cdot (\gamma - 1)$$

where, α: Percentage increase in the pipeline frictional loss factor when conveying mud-flow

β: Soil coefficient (shown in Table 4.2.4)

γ: Density of mud-flow (measured values)

[1] Integration Standards for Civil Works, Ministry of Land, Infrastructure and Transport

Table 4.2.4 Soil Coefficient (Criteria[1])

Soil property	β
Clay/silt	2
Fine sand / Normal sand	3
Coarse sand / Gravel mixed sand	4
Gravel	5

Source: JICA Study Team

In the final test, soil coefficients (β) at each depth are calculated from the pipeline friction coefficient in the operation with clear water and the pipeline head loss in the dredging operation. The detail and average at each depth are shown in Table 4.2.5 and 4.2.6, respectively. It is considered that the calculated soil coefficients are appropriate judging from the soil condition at the final test site.

Table 4.2.6 Soil Coefficient (In final test at Wonogiri Reservoir)

Depth		0 – 1 m	1 – 2 m	2 – 3 m
Soil	Clay	1.5	―	―
	Sandy silt	―	2.5	4.0

Source: JICA Study Team

4.2.3 Pipe Flow Velocity and Density

The data on the flow rate and density of sediments in the pipeline that were sucked in front of the intake and at A-2 area are shown in Figures 4.2.5 to 4.2.7 below. The characteristic thereof are derived as follows:

i) During the operation of the final test, the density largely changed as shown in Figures 4.2.5 to 4.2.7. This seems to show the effects of clearance between the sediment surface and suction mouth.

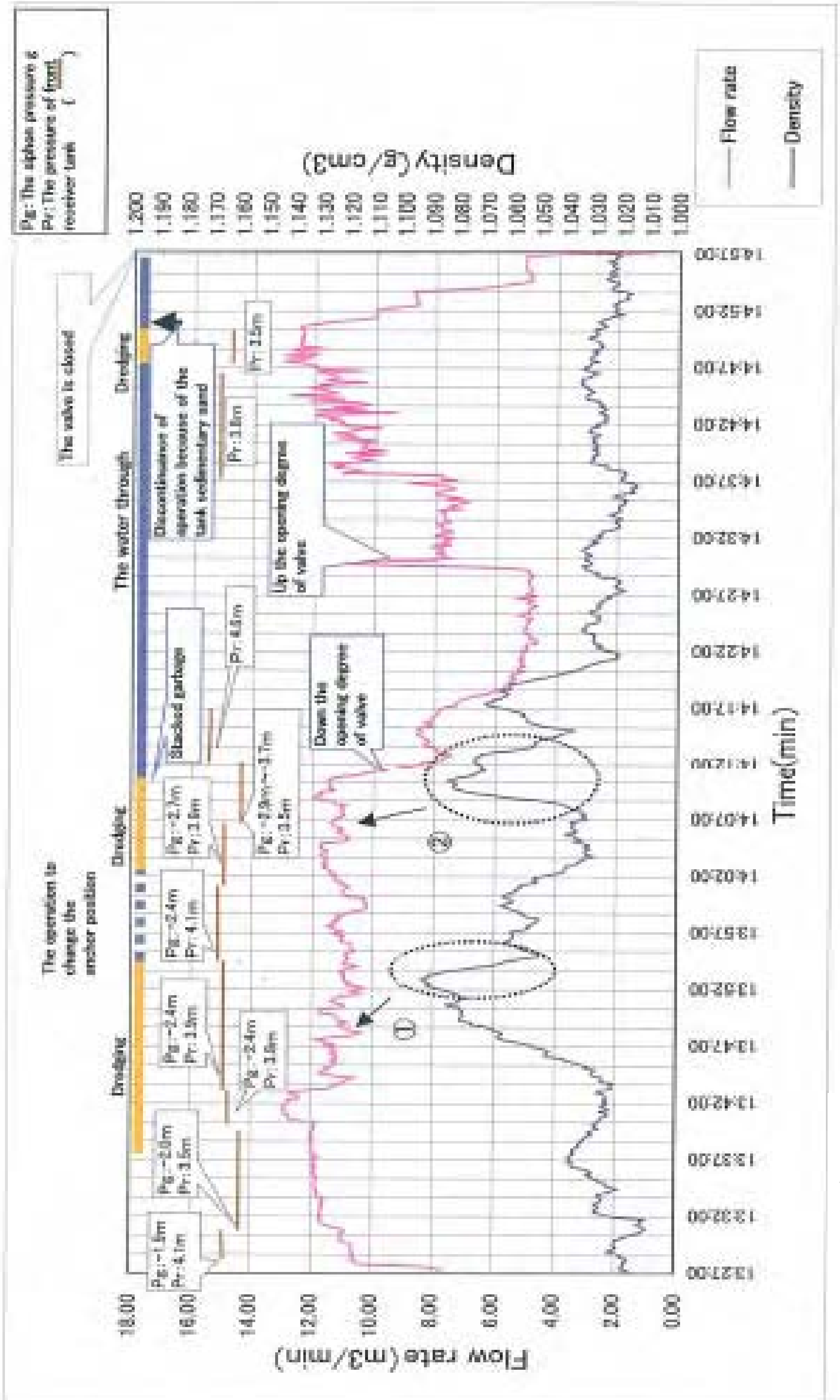
ii) When such peaks in density curve as points ①, ②, ⑥, ⑦, ⑧ and ⑪ shown in Figures 4.2.5 and 4.2.7 take place, dredging work was stopped and clear water was inserted into the pipe, because the flow rate and density showed the values which were likely to cause deformation of the pipe. Since the density showed a value of 1.05 – 1.06 g/cm^3 even when clear water had been inserted, it was inferred that sediments had been deposited in the pipe and flow velocity had been close to the critical one.

iii) When such peaks in density curve as points ③, ④, ⑤, ⑨ and ⑩ shown in Figures 4.2.6 to 4.2.7 take place, it was inferred that sediments were moving at a velocity exceeding the critical one, because the density was smaller than those at the points mentioned ii) above on the condition that the flow rate was increasing or constant.

Table 4.2.5 Calculation of Soil Coefficient

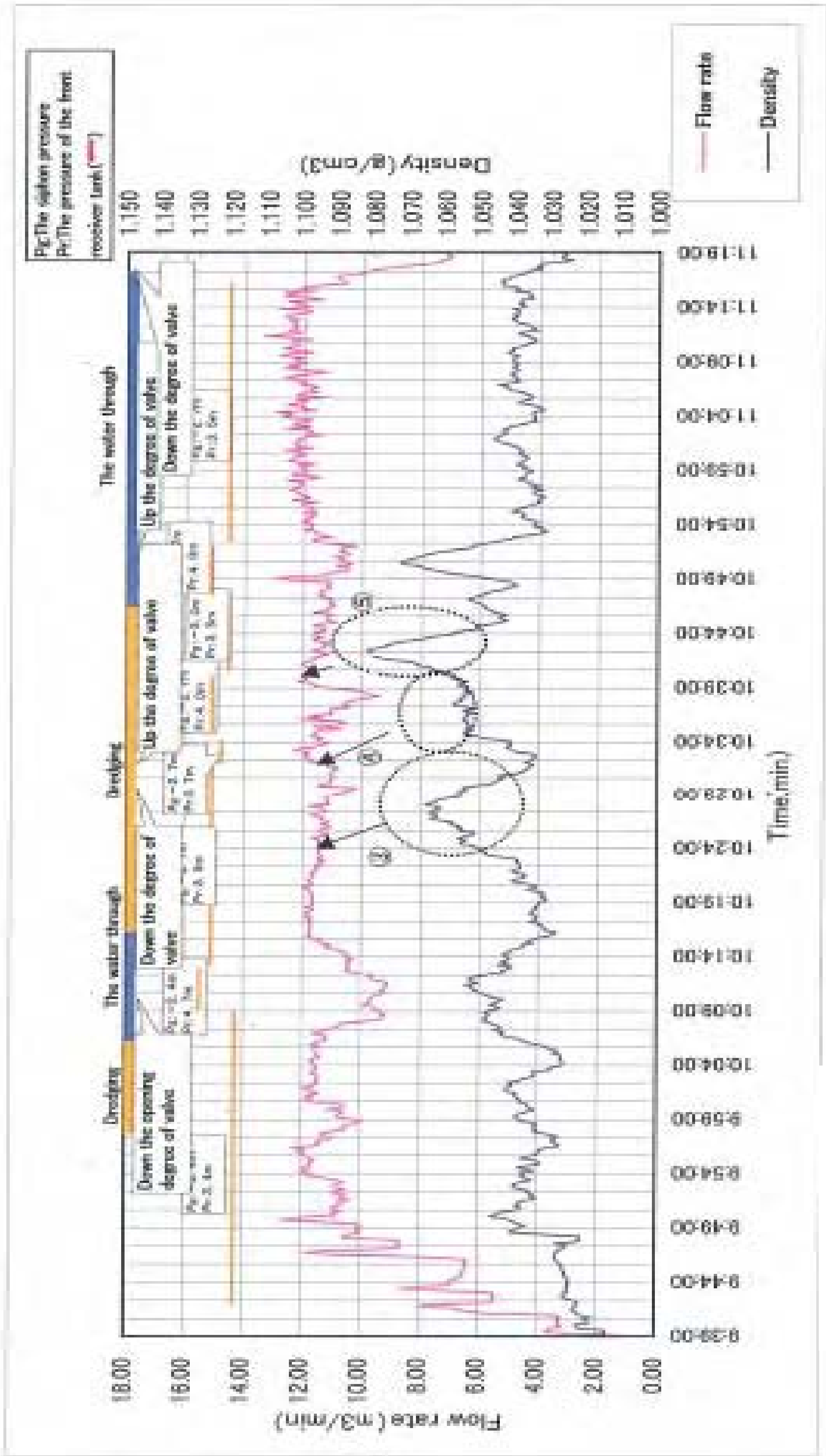
In case od Clear Water						(Pipe Length = 297.4m)			
Flow Rate	(m^3/min.)	10.63	12.26	13.11	9.49	13.00	5.40	8.71	
Flow Velocity in Pipeline	(m/s)	1.41	1.63	1.74	1.26	1.73	0.72	1.16	
Density	(g/cm^3)	1	1	1	1	1	1	1	
Actual measured value of the pressure gauge on Barge (PG1: after correction of gauge height)	(m)	-1.14	-1.14	-1.11	-1.08	-1.07	-1.07	-1.07	
Actual measured value of the pressure gauge on Gate (PG2: after correction of gauge height)	(m)	-1.90	-2.07	-2.24	-1.73	-2.24	-1.06	-1.90	
Actual measured value of the pressure gauge in front of Receiving Tank (PG3: after correction of gauge height)	(m)	4.88	4.21	3.94	5.08	3.94	6.30	5.56	
Head between the center of the gate pipe and the center of the pipe at Receiving Tank	hc(m)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	
Head loss betwewen Barge and Gate (measured value)	(m)	0.85	1.02	1.22	0.74	1.26	0.08	0.92	
Head between the center of the gate pipe and the center of the pipe at Receiving Tank	hd(m)	7.80	7.80	7.80	7.80	7.80	7.80	7.80	
Head loss between Barge and Gate (measured value)	(m)	1.02	1.52	1.62	0.99	1.62	0.44	0.34	
Pipeline head loss (measured value)	(m)	1.87	2.54	2.84	1.73	2.88	0.52	1.26	Average
Pipeline frictional loss (measured value)	(m)	0.0248	0.0253	0.0247	0.0288	0.0255	0.0269	0.0250	0.0258
In case od Dredging									
Flow Rate	(m^3/min.)	9.889	10.325	10.761	11.024	11.958	11.989	12.000	11.354
Flow Velocity in Pipeline	(m/s)	1.31	1.37	1.43	1.46	1.59	1.59	1.59	1.51
Density	(g/cm^3)	1.073	1.068	1.078	1.052	1.050	1.037	1.039	1.055
Actual measured value of the pressure gauge on Barge (PG1: after correction of gauge height)	(m)	-1.14	-1.14	-1.11	-1.11	-1.11	-1.07	-1.07	-1.11
Actual measured value of the pressure gauge on Gate (PG2: after correction of gauge height)	(m)	-1.90	-2.07	-2.07	-2.07	-2.41	-2.24	-2.24	-2.24
Actual measured value of the pressure gauge in front of Receiving Tank (PG3: after correction of gauge height)	(m)	4.88	4.73	4.34	4.34	4.14	4.00	3.94	4.07
Head between the center of the gate pipe and the center of the pipe at Receiving Tank	hc(m)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Head loss betwewen Barge and Gate (measured value)	(m)	0.85	1.02	1.05	1.05	1.39	1.26	1.26	1.22
Head between the center of the gate pipe and the center of the pipe at Receiving Tank	hd(m)	7.80	7.80	7.80	7.80	7.80	7.80	7.80	7.80
Head loss between Barge and Gate (measured value)	(m)	1.02	1.00	1.39	1.39	1.25	1.56	1.62	1.49
Pipeline head loss (measured value)	(m)	1.87	2.02	2.44	2.44	2.64	2.82	2.88	2.71
Pipeline frictional loss (measured value)	(m)	0.0286	0.0284	0.0315	0.0301	0.0277	0.0294	0.0300	0.0315
Dredging depth	(m)	0 - 1	0 - 1	1 - 2	1 - 2	1 - 2	2 - 3	2 - 3	2 - 3
Percentage increse in pipeline frictional loss factor (measured value) α		1.11	1.10	1.22	1.17	1.07	1.14	1.16	1.22
Soil coefficient $\beta = (\alpha - 1)/(\gamma - 1)$		1.50	1.46	2.86	3.17	1.44	3.74	4.15	3.98

Source: JICA Study Team



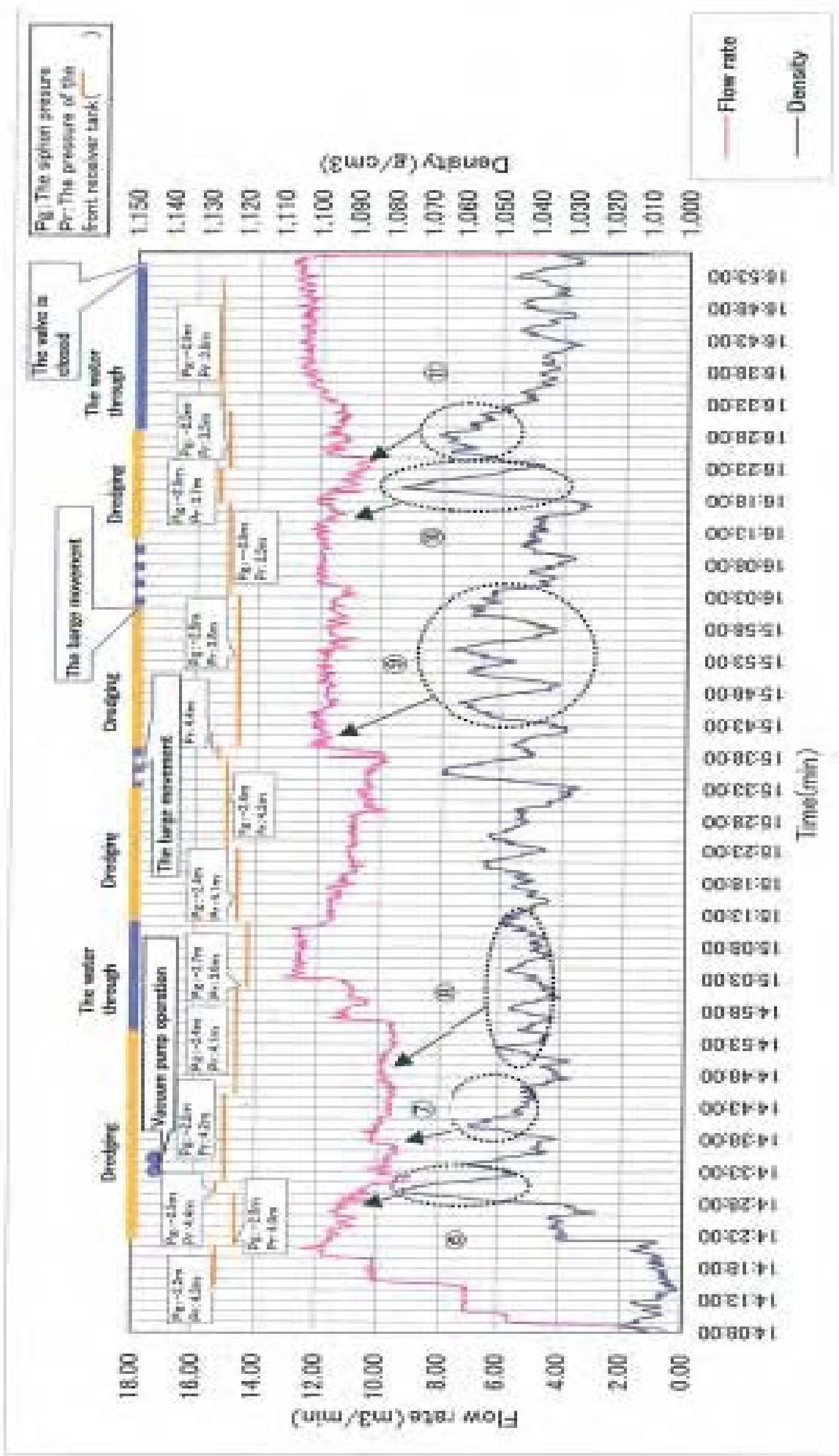
Source: JICA Study Team

Figure 4.2.5 Relationship between Flow and Density (in front of Intake)



Source: JICA Study Team

Figure 4.2.6 Relationship between Flow and Density (A-2 Area)



Source: JICA Study Team

Figure 4.2.7 Relationship between Flow and Density (A-2 Area)

The relationship between the pipe flow velocity and density at each peak point is shown in Table 4.2.7 and Figure 4.2.8 with a graph of the critical velocity given by the following equation for each particle size.

$$Vc = 5 \times C^{1/3} \times D^{1/2} \times (4.5 - 1/ds^{1/2})^{5/6}$$

where;

Vc: Critical velocity

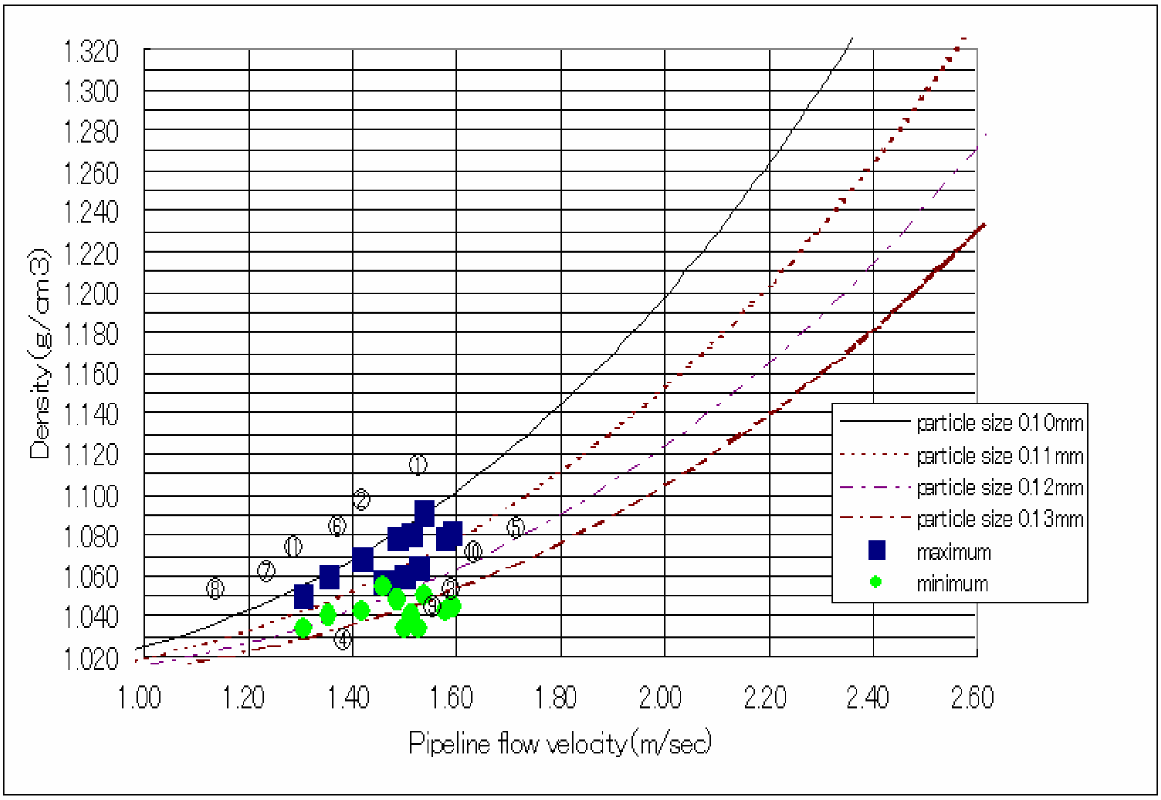
C: Absolute volumetric sediment concentration (%)

D: Pipe diameter

ds: Representative particle size of sediments (mm)

Notes; a) Volumetric sediment concentration was calculated from a relationship between the absolute volumetric concentration and density, which is shown in Figure 4.2.9.

b) Based on the results of laboratory test for soil samples taken at point B-3, the representative particle size of the dredged sediment was derived at 0.1 mm, which corresponds to a 60% diameter of particle size in the particle size distribution curve.



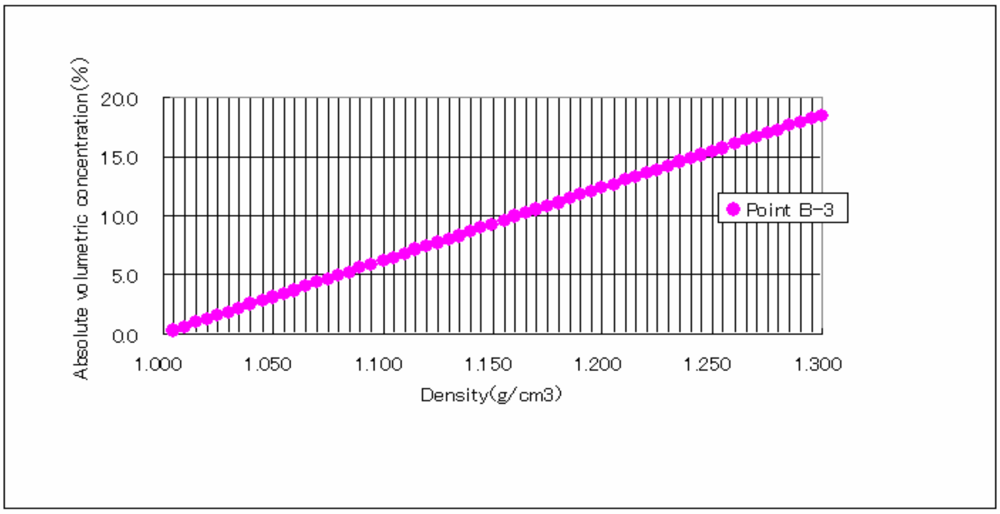
Source: JICA Study Team

Figure 4.2.8 Flow Velocity and Density of Sediment in Pipeline

Table 4.2.7 Flow Velocity and Density in Pipeline

Point	Flow Rate (m3/min.)	Measured Velocity (m/s)	Critical Velocity (Ds=0.1mm) (m/s)	Density (g/cm^3)	
				Minimum	Maximum
1	11.6	1.54	1.51	1.050	1.091
2	11.4	1.51	1.45	1.040	1.080
3	11.5	1.53	1.35	1.034	1.064
4	11.0	1.46	1.24	1.054	1.057
5	12.0	1.56	1.45	1.045	1.081
6	11.2	1.49	1.45	1.048	1.078
7	10.2	1.35	1.32	1.040	1.060
8	9.9	1.31	1.32	1.034	1.050
9	11.3	1.50	1.32	1.034	1.060
10	11.9	1.58	1.45	1.043	1.078
11	10.7	1.42	1.35	1.043	1.068

Source: JICA Study Team



Source: JICA Study Team

Figure 4.2.9 Relationship between Absolute Volumetric Concentration and Density

The maximum flow values shown at points ①, ②, ⑥, ⑦, ⑧ and ⑪ in Figures 4.2.5 and 4.2.7 above are well agreeable with the critical velocities for a particle size of 0.1 mm, that are estimated applying the above equation. This particle size is in close agreement with the average of the representative particle size of sediments at a depth of 4 m at B-3 point, which is 0.093 mm. Accordingly, it can be said that the above equation to estimate the critical velocity shows good agreement with the results of the final test as a whole.

To keep the stable density in this system, it is needed to be operated with the velocity more than the critical velocity in the pipeline.

4.2.4 Dredging Depth

Based on the measurement with a sounding rod before and after the dredging operation, it is estimated that the suction pipe tip reaches a depth of approximately 4.0 m from surface of sediment deposit. Though a tendency of consolidation was found in the result of the core drilling, there were no serious problems that made the dredging difficult. With this method, it is possible to excavate the sediment to 4m depth where sediment is composed of clay, silt, sandy silt, and sandy clayey silt.

4.2.5 Sediment Removal Amount

(1) Sounding Survey

Based on the sounding survey using the sounding rod before and after the operation, it is estimated that the amount of sediment removed is approximately 146 m^3 as shown in Table 4.2.8.

Table 4.2.8 Sounding Result of Sediment Removal Amount

Area	Excavator	Volume of Sediment Removed (m^3)
A-1	Water jet nozzle	3.8
A-1	Side rotary	8.1
A-1	Side rotary (No power)	4.9
A-2	Side rotary	122.2
I-1	Side rotary	7.3
Total		146.2

Source: JICA Study Team

(2) Amount of Sediment in Receiving Tank and Storage Tank

The sediment amount stored in the receiving tank and storage tank is approximately 69 m3 as shown in Table 4.2.9. It is considered that all of the sandy components in the dredged sediment accumulated in the receiving tank, while silt and clay were returned to the reservoir. The amount of the latter soils is calculated approximately at 77m^3 (= 146m^3 – 69m^3).

Table 4.2.9 Amount of Sediment in Receiving Tank

Tank	Accumulated amount (m^3)
Receiving Tank	5.6
Storage Tank	63.5
Total	69.1

Source: JICA Study Team

(3) Sediment amount derived from the measured value of density meter and flow meter

The dredged sediment amount is calculated using the following equation and the calculation results are shown in Table 4.2.10 below:

$$V=\Sigma Qt \times \Delta t \times ((\gamma - 1)/(\gamma s - 1)/(1 - P/100)) \times 100$$

where ;

V: Dredged amount (m^3)

Qt: Discharge rate (m^3/s)

Δt: Time (13.1 hours)

γ: Specific gravity of sediment flow (g/cm^3)

γs: Specific gravity of soil particle (g/cm^3)

P: Pressure of soil particle (%)

Table 4.2.10 Calculated Amount of Dredged Sediment

Area	Excavator	Volume of Sediment Volume (m^3)
A-1	Water jet nozzle	2.4
A-1	Side rotary	5.4
A-1	Side rotary (No power)	3.9
A-2	Side rotary	134.8
I-1	Side rotary	15.4
Total		161.9

Source: JICA Study Team

As shown in tables above, the dredged sediment volume derived from the results of sounding data is almost equal to the value calculated based on records of density meter and flow meter. The amount of the sediment during water passing through in the pipe is estimated approximately at 16m^3 (= 162m^3 – 146m^3).

Hence, it is roughly estimated that dredging of 140 to 160 m^3 would be possible using the water level difference encountered in this verification test.

4.2.6 Debris and Garbage

In the final test, the garbage shown in Table 4.2.11 and Photos below passed through the pipeline and finally reached the receiving tank. This system is free of clogging after the garbage once passed through the suction mouth. Accordingly, this system has a high reliability to effectively remove the sediments mixed with vegetative debris and garbage in front of the intake structure, although it was one of the issues on the hydro-suction system that was needed to be clarified in this verification test.

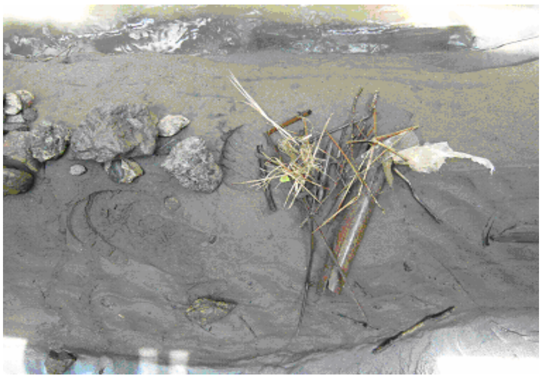
If obstruction at the suction mouth such as the screen is eliminated, the excavator can dredge the reservoir deposits whose sizes are slightly less than diameter of hole on the pipe. Hence, it has a possibility to remove more effectively debris and garbage from the reservoir bottom through improvement of the system in the near future.

Table 4.2.11 Garbage and Pebbles Removed by the Hydro-Suction System

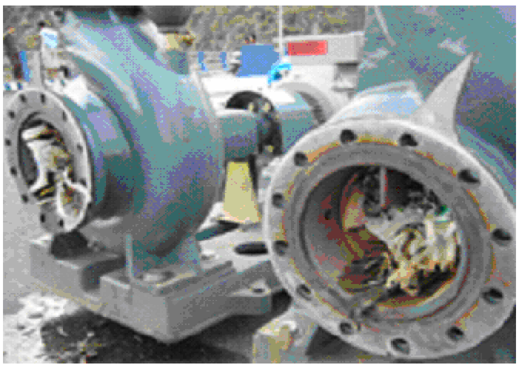
Sort	Dimensions
Pebble	Maximum diameter of 130 mm
Bamboo, stalk	Maximum length of about 600 mm x width of about 50 mm
Plastic	Scraps with size of 150 mm x 150 mm

Source: JICA Study Team

Removed Pebbles and Garbage



Removed Pebbles, Garbage and Sand



Clogging of Return Pump with Garbage

Clogging of Valve with Garbage

4.3 Applicability to Wonogiri Reservoir Sediment Management

Main results of the verification test are summarized below:

(1) The verification test clarifies that the sediment removal system using a difference in water levels can be applied to dredging of sediments in front of the intake structure at Wonogiri Multipurpose Dam site.

(2) It was found that excavation device, especially a side-rotary type excavator, was of big effect on efficient dredging.

(3) When a flow rate in the sediment passing pipe was around 12m^3/min, density and volumetric sediment concentration conveyed by the system were approximately 1.09 g/cm^3 and 13%, respectively.

(4) The capacities of this system consisting of a type of the side rotary-type excavator device are as follows:

① Dredging rate per unit of time is about 30 m^3/hour.
② Dredging rate per unit of power is about 8 m^3/kWh.
③ Water consumption per unit of dredged sediment is19 m^3/min.
④ Dredging depth is about 4 m.

(5) Since those values were secured with controlled condition under a maximum, high ability could be expected at full capacity.

(6) Trash including small stones with a maximum diameter of 130mm, bamboo with a maximum length of about 600mm, and vinyl with a size of approximately 150mm x 150mm passed through the siphon system.

(7) The soil coefficient used to estimate the frictional loss factor for sediment materials in Wonogiri Reservoir is around 1.5 for clay and around 2.5 for sandy silt.

Consequently, this hydro-suction system is applicable to sediment removal at the intake structure in Wonogiri Reservoir in order to keep the proper function of the intake structure. In the subsequent study, it is necessary to examine the safety measures against flood, although the verification test was carried out in dry season when no flood takes place.

CHAPTER 5 WONOGIRI RESERVOIR SEDIMENT MANAGEMENT PLAN

5.1 Wonogiri Reservoir Sediment Management Plan

The verification test for the hydro-suction system, which was carried out in the field, showed that this system would be applicable to remove sediments at the intake structure in Wonogiri Reservoir. Hereinafter, Wonogiri Reservoir Sediment Plan by the hydro-suction sediment removal system is described.

In consideration of river environment, it is not desirable to operate this system by itself. It is necessary to mitigate discharge water with high concentration as not to reach downstream. Therefore, the use of this system is divided into two(2) ways, one is in flooding time and the other in the power plant operation time.

5.1.1 In Flooding Time

(1) Operation Time

Averting of danger, the operation time is limited the flooding time over 100 m^3/s and below 800 m^3/s of the inflow.

The averaged flooding time over 100 m^3/s and below 800 m^3/s of the inflow from December to April in the period of 1993 to 2004 is 732 hours. The operation time is estimated 183 hours excluding night-time and preparation time for operating, which is assumed to be 75 % of the total hours.

(2) Reservoir Water Level

The reservoir water level of the above-mentioned period is roughly estimated EL.133.64 m.

(3) Dredging Area

Dredging area is determined in front of the intake as shown in Figure 5.1.1.

(4) Calculation of Sediment Removal Amount

The "Darcy-Weisbach" formula, as shown below, is used to calculate the pipeline head loss.

$$H = \alpha \cdot \lambda \cdot \gamma \frac{v^2}{2g} \times \frac{L}{D}$$

where ;

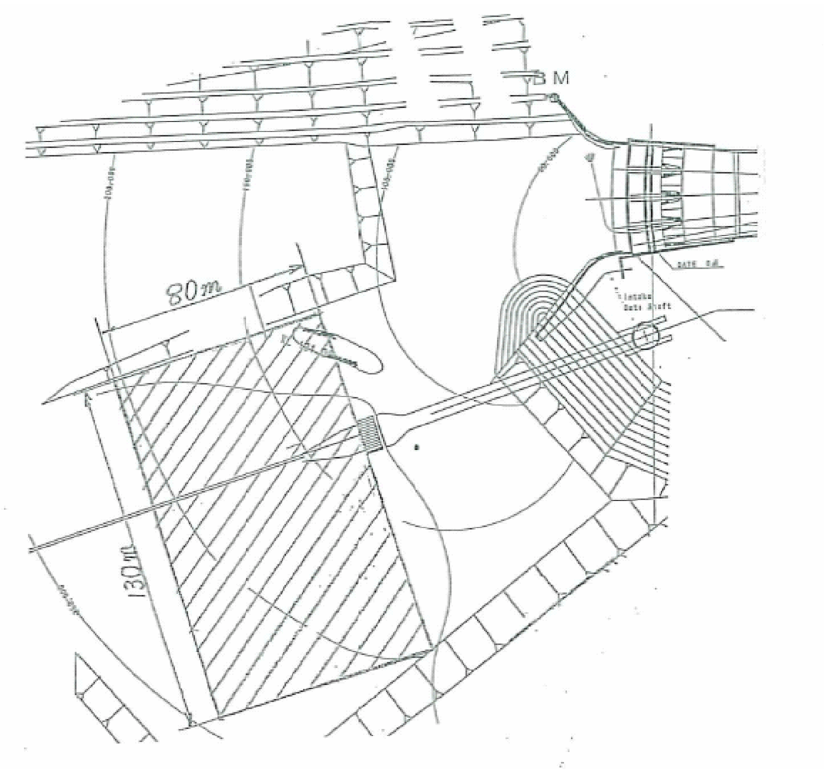
H : Pipeline head loss (m)

Pipeline head loss is necessary to be less than the head between the reservoir water level and the outlet elevation.

H<18.64 m (=133.64 m – 115.00 m)

α : Percentage increase in the pipeline frictional loss factor when conveying mud-flow

α=1+β(γ-1) β : Soil coefficient ; 4.0 is adopted considering soil test



Source: JICA Study Team

Figure 5.1.1 Dredging Area

γ : Density of mud flow

λ : Pipeline friction coefficient at clear water (=0.0258)

L : Pipeline length (m) 500m (=240m (Spillway side) + 250m (Reservoir side))

D : Diameter of the pipe (ϕ 600 mm)

v : Flow velocity (m/s)

The density of mud-flow is estimated 1.19 on the premise that the flow velocity v = 2.2 m/sec and particle size 0.11mm in Figure 5.1.2. (Based on the results of soil mechanical test at B-3 point.)

The percentage increase of the pipeline frictional loss factor during suction, α is 1.76 (=1+4 x (1.19-1)). The pipeline flow velocity for practical use is estimated 2.7 m/s, 1.2 times of the critical flow velocity so as to ensure suction.

The pipeline head loss H is estimated 11.12 m as follows, and it is small compared to the head between the reservoir water level and the outlet elevation. Consequently, the affordable suction is possible.

$H = 1.76 \times 1.19 \times 0.0258 \times 2.2^2 / 19.6 \times 500 / 0.6$

$= 11.12\ m < 18.64\ m\ (= 133.64\ m - 115.00\ m)$

The suction rate is calculated using the following equation.

$Q' = (\pi/4) \times D \times D \times V \times (C'/100)$

where;

Q' : Suction rate per unit time (m^3/s)

D : Diameter of the pipe (ϕ 600 mm)

V : Practical flow velocity (m/s)

C' : Volumetric sediment concentration (%)

As the volumetric sediment concentration in the density of 1.19, is obtained 25% in Figure 5.1.3, the suction rate is calculated 0.19 m^3/s as shown below.

$Q' = (\pi/4) \times 0.6 \times 0.6 \times 2.7 \times (25/100)$

$= 0.19\ m^3/s$

When the volumetric sediment concentration is 25 % and the diameter of the pipe is ϕ 600 mm, the critical flow velocity is obtained 2.5 m/s in Figure 5.1.4. There will be no problem of sediment accumulation in the pipe with the practical flow velocity exceeding the critical flow velocity.

Suction amount is estimated approximate 125,200 m^3 as follows:

$Q = Q' \times T$

$= 0.19\ m^3/s \times 183 \times 3600$

$= 125{,}200\ m^3$

where;

Q : Suction amount (m^3)

Q' : Suction rate per unit of time (m^3/s)

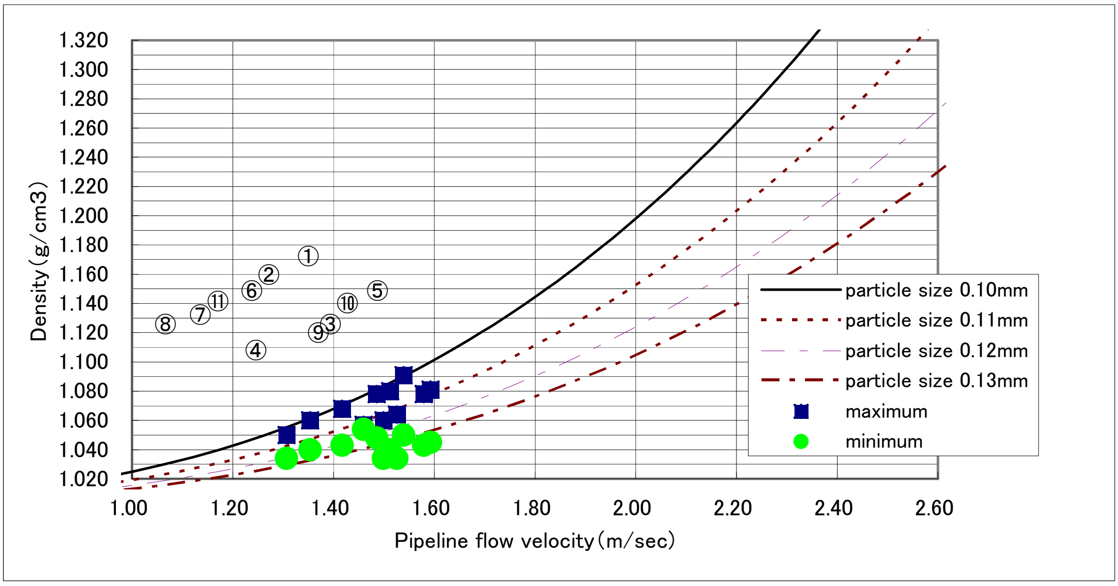
T : Operation time (sec.)

The summary of the suction in flooding time is shown in Table 5.1.1.

Table 5.1.1 Suction Amount in Flooding Time

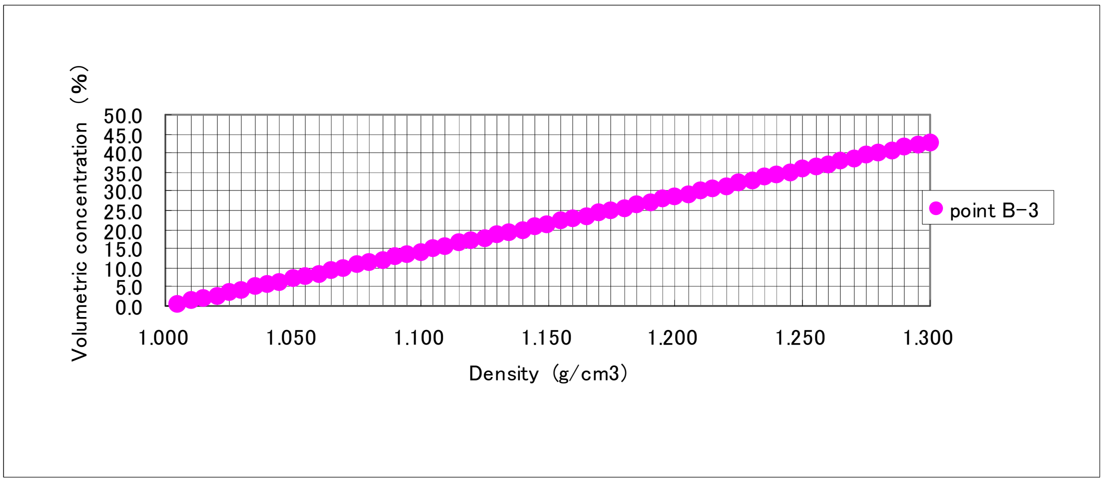
Operation time (hrs.)	Pipe flow velocity (m/s)	Volumetric sediment concentration (%)	Suction rate per unit time (m^3/s)	Suction amount (m^3)	Water consumption (m^3)
183	2.7	25	0.19	125,200	502,700

Source: JICA Study Team



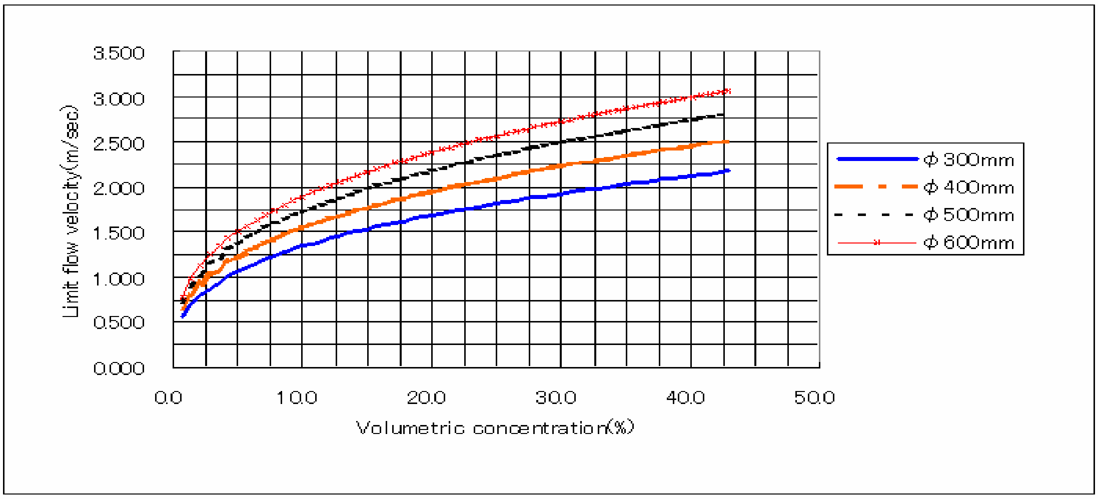
Source: JICA Study Team

Figure 5.1.2 Critical Flow Velocity and Density



Source: JICA Study Team

Figure 5.1.3 Density and Volumetric Consistency



Source: JICA Study Team

Figure 5.1.4 Volumetric Sediment Concentration and Critical Flow Velocity

5.1.2 In Power Plant Operation Time

As abone-mentioned, this system can remove the sediment amount of 125,200 m^3 in flooding time. On the other hand, extremely high concentration of discharge flow as 25% of volumetric sediment concentration, run down to downstream of Wonogiri Dam. And it might be a large impact on the environment of river.

The following index has been proposed for the evaluation of the impact on fish in Canada. This index was introduced and has been used on trial in Japan, and SI of 10 is a standard for water quality management.

SI = loge(SS * T)

where ;

SI : Stress Index

SS : Suspended Solids (mg/l)

T : Duration (hour)

Table 5.1.2 shows SI value of the discharge flow in scale mixed with the suction discharge flow, 25% and 7% of volumetric sediment concentration respectively. And the scale more than 100 m^3/s of the flow are estimated for reference. On the assumption of discharge flow scale as 30 m^3/s of the average of the power plant discharge flow, the hydro-suction system with 25% of volumetric sediment concentration is limited to less than 3 hour-operation under SI of 10, while in case of 7% of volumetric sediment concentration, it is free from restraint .

4-hour operation time of the hydro-suction system with 7% of volumetric concentration is preferable and affordable to the environment of river because of SI value less than 9.

Table 5.1.2 Stress Index

		Hydro-suction discharge (25%)						Hydro-suction discharge (7%)					
		T (hrs.)						T (hrs.)					
		1	2	3	4	5	6	1	2	3	4	5	6
Power plant discharge	10m^3/s (SS=100)	9.8	*10.5*	*10.9*	*11.2*	*11.4*	*11.6*	8.3	9.0	9.4	9.7	9.9	*10.1*
	30m^3/s (SS=500)	8.9	9.5	9.9	*10.2*	*10.5*	*10.6*	7.6	8.2	8.7	8.9	9.2	9.3
	50m^3/s (SS=700)	8.4	9.1	9.5	9.8	*10.0*	*10.2*	7.3	8.0	8.4	8.7	9.0	9.1
	75m^3/s (SS=900)	8.2	8.9	9.3	9.6	9.8	*10.0*	7.3	8.0	8.4	8.7	8.9	9.1
Spill-out flow	100m^3/s (SS=1,000)	8.0	8.7	9.1	9.4	9.6	9.8	7.3	8.0	8.4	8.6	8.9	9.1
	200m^3/s (SS=1,500)	7.8	8.5	8.9	9.2	9.4	9.6	7.4	8.1	8.5	8.8	9.1	9.2
	300m^3/s (SS=2,000)	7.9	8.6	9.0	9.3	9.5	9.7	7.7	8.4	8.8	9.1	9.3	9.5
	600m^3/s (SS=3,000)	8.1	8.8	9.2	9.5	9.7	9.9	8.0	8.7	9.1	9.4	9.6	9.8

Source: JICA Study Team

(1) Operation Time

Operation time is assumed 480 hours, 4 hours time 120 days for a period of five months from December to April in rainy season.

(2) Reservoir Water Level

The reservoir water level during December to April is EL.133.64 m as mentioned in the section of 5.1.1.

(3) Calculation of Sediment Removal Amount

The pipeline head loss and sediment removal amount are calculated using the "Darcy-Weisbach" formula, Equation-1 and Equation-2. The results of pipeline head loss and removal sediment amount are shown in Table 5.1.3 and Table 5.1.4, respectively.

$$H = \alpha \cdot \lambda \cdot \gamma \frac{v^2}{2g} \times \frac{L}{D}$$ the "Darcy-Weisbach" formula

Q'=(π /4) x D x D x V x (C'/100) Equation-1

Q = Q' x T Equation-2

Table 5.1.3 Pipeline Head Loss

α	γ	λ	D	L	v	H
1.4	1.1	0.0258	ϕ 600	500	1.8	8.2

Source: JICA Study Team

where ;

H : Pipeline head loss (m) H<18.64 m (=133.64 m – 115.00 m)

α : Percentage increase in the pipeline frictional loss factor when conveying mud-flow, α=1+β(γ-1) β: Soil coefficient

γ: Density of mud-flow

λ : The pipeline friction coefficient at clear water

L : Pipeline length (m)

D: Diameter of the pipe

v : Flow velocity (m/s)

Q': Suction rate per unit time (m^3/s)

Q: Suction amount (m^3)

Table 5.1.4 Suction Amount in Power Plant OperationTime

Operation time (hrs.)	Pipe flow velocity (m/s)	Volumetric sediment concentration (%)	Suction rate per unit time (m^3/s)	Suction amount (m^3)	Water consumption (m^3)
480	2.2	7	0.04	69,100	1,074,300

Source: JICA Study Team

5.1.3 Wonogiri Reservoir Sediment Removal Management Plan

Conclusively, Hydro-suction sediment removal system operation in Wongiri Reservoir is designed to be compounded of Power plant operation time and Flooding time, as shown in Table 5.1.5, aiming at suction amount of 100,000 m^3.

Table 5.1.5 Suction Operation in Wonogiri Reservoir

Division	Operation time (hrs.)	Pipe flow velocity (m/s)	Volumetric sediment concentration (%)	Suction rate per unit time (m^3/s)	Suction amount (m^3)	Water consumption (m^3)
Power plant operation time	480	2.2	7	0.04	69,100	1,074,300
Flooding time	46	2.7	25	0.19	31,500	126,400
Total	526	-	-	-	100,600	1,200,700

Source: JICA Study Team

Figure 5.1.5 shows the plan of the hydro-suction sediment removal system in Wonogiri Reservoir. And the detail of the siphon barge is shown in Figure 5.1.6.

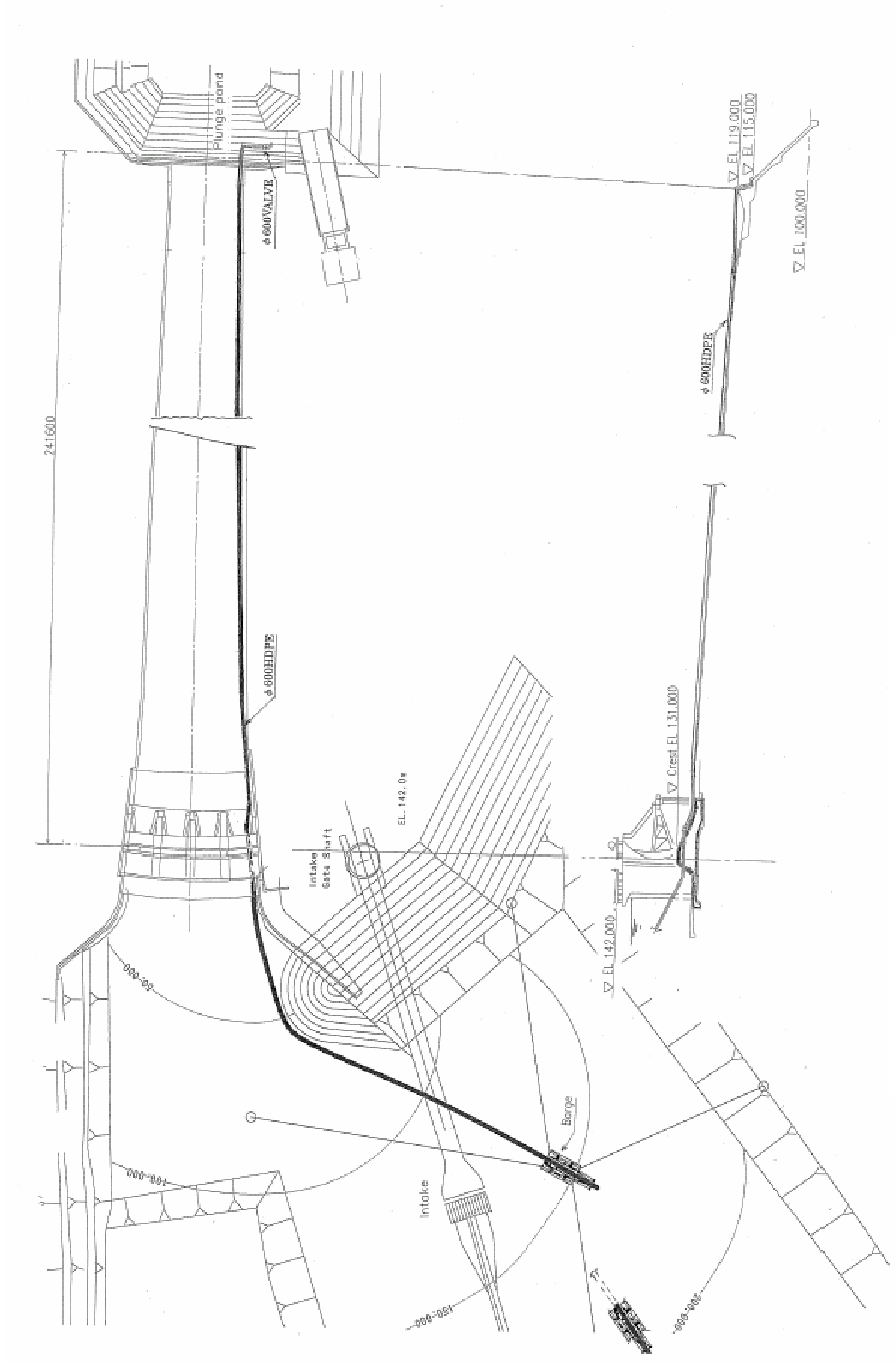
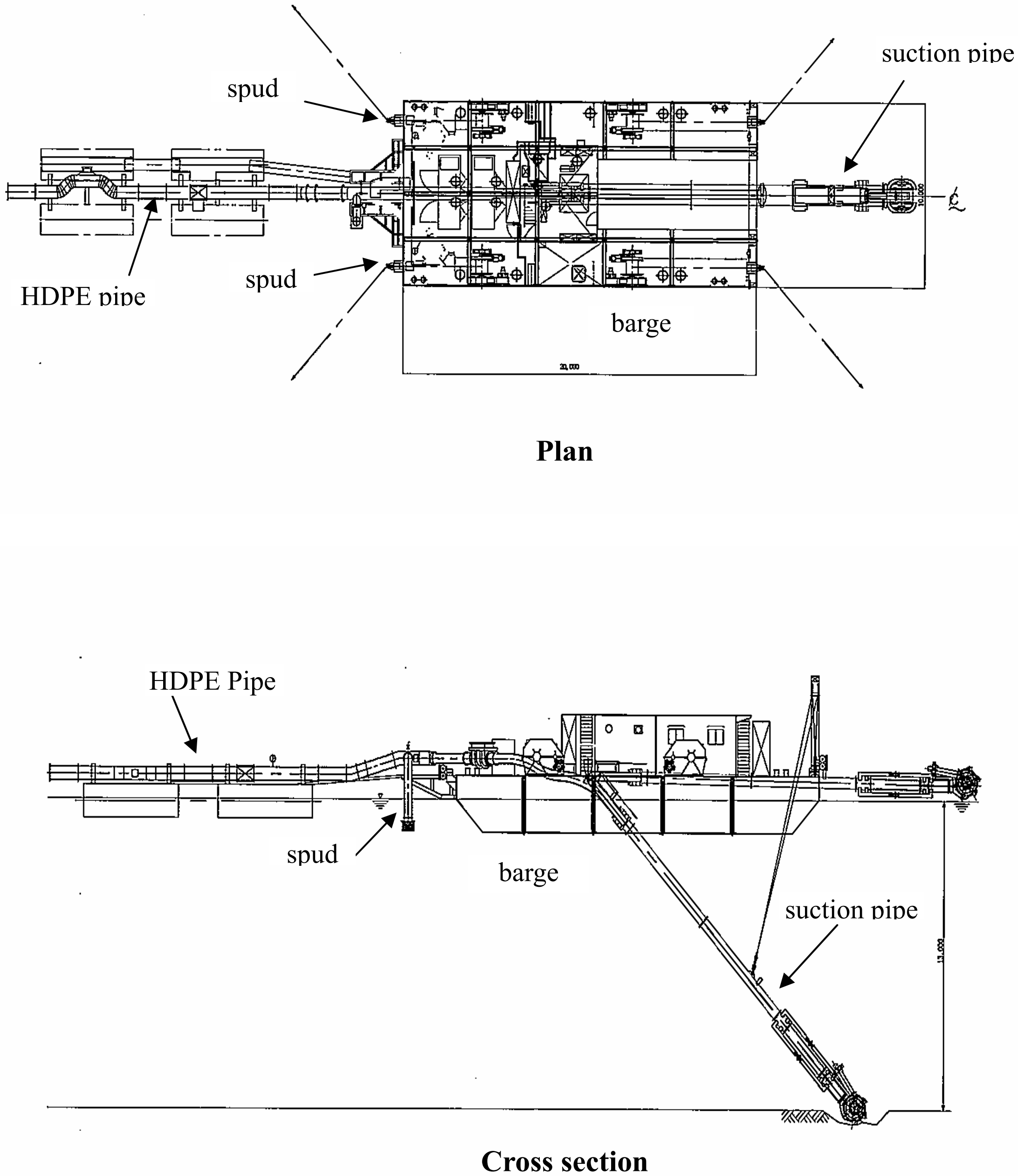


Figure 5.1.5 Plan of Hydro-suction Sediment Removal System

Source: JICA Study Team



Source: JICA Study Team

Figure 5.1.6 Detail of Siphon Barge

5.2 Cost Estimate

5.2.1 Conditions

(1) Currency and Exchange Rate

Cost of hydro-suction sediment removal system is estimated in U.S. Dollar. The following exchange rate as of December 2005 is adopted:

US $ 1.0 = Yen119.63

where, US $: U.S. Dollar

Yen : Japanese Yen

(2) Discount Rate

A discount rate of 12% is adopted.

5.2.2 Cost Estimate

(1) Cost Components

Cost for hydro-suction sediment removal system comprises i) Equipment cost, ii) Operation and Maintenance cost. The equipment cost consists of i) Siphon Barge and others, ii) Devices. Table 5.2.1 shows the equipment cost and an annual O&M cost of hydro-suction sediment removal system. The cost of Hydro-suction Sediment Removal System in 11 years and 50 years are shown in Table 5.2.2 and 5.2.3, respectively. The net present value of those cost is estimated as shown in Table 5.2.4.

Table 5.2.1 Cost of the Hydro-suction Sediment Removal System

Description	Unit	Quantity	Unit Cost US$	Cost US$,thousand	Remarks
Equipment cost					
Siphon Barge	nr	1	2,006,000	2,006	11-year of service life
Anchor holding Boat	nr	1	222,000	222	22-year of service life
Tender Boat	nr	1	14,000	14	22-year of service life
HDPE Pipe (12m-long)	pcs	19	8,939	170	12-year of service life
HDPE Pipe (18m-long)	pcs	14	10,519	147	12-year of service life
Joint	pcs	20	3,661	73	6-year of service life
Float	pcs	35	6,955	243	6-year of service life
Sub Total				2,875	
O&M cost					
Operation cost	unit	1	35,154	35	Suction amount of 100,000m^3/year
Maintenance cost	unit	1	2,508	3	Annual Maintenance
Sub Total				38	
Total				2,913	

Source: JICA Study Team

Table 5.2.2 Cost of Hydro-suction Sediment Removal System in 11 years (Unit:1000 US$)

			1-year	2-year	3-year	4-year	5-year	6-year	7-year	8-year	9-year	10-year	11-year	Total
Hydro-Suction System	Equipment Cost	Barge	2,006.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,006.2
		Anchor Handling Boat	221.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	221.5
		Tender Boat	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.9
		HDPE Pipe(12m)	169.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	169.8
		HDPE Pipe(18m)	147.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	147.3
		Joint	73.2	0.0	0.0	0.0	0.0	0.0	73.2	0.0	0.0	0.0	0.0	146.5
		Float	243.4	0.0	0.0	0.0	0.0	0.0	243.4	0.0	0.0	0.0	0.0	486.8
		Subtotal	2,875.3	0.0	0.0	0.0	0.0	0.0	316.6	0.0	0.0	0.0	0.0	3,192.0
	Operation and Maintenance cost	Operation	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	386.4
		Maintenance	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	27.6
		Subtotal	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	414.0
	Total Cost		2,913.0	37.6	37.6	37.6	37.6	37.6	354.3	37.6	37.6	37.6	37.6	3,605.9
	Cumulative Cost (A)		2,913.0	2,950.6	2,988.2	3,025.9	3,063.5	3,101.1	3,455.4	3,493.0	3,530.7	3,568.3	3,605.9	

Source: JICA Study Team

Table 5.2.4 The Net Present Value of the Hydro-suction Sediment Removal System Cost

(Thousand US$)

Description	11-year period		50- year period	
	Cost	NPV	Cost	NPV
Equipment Cost	3,192	2,710	14,539	3,629
O&M cost	414	223	1,882	313
Total	3,606	2,933	16,421	3,942

Note : NPV means net present value.

Source: JICA Study Team

Table 5.2.3 Cost of Hydro-suction Sediment Removal System in 50 Years

			1-year	2-year	3-year	4-year	5-year	6-year	7-year	8-year	9-year	10-year	11-year	12-year	13-year	14-year	15-year	16-year	17-year
Hydro-Suction System	Equipment Cost	Barge	2,006.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,006.2	0.0	0.0	0.0	0.0	0.0
		Anchor Handling Boat	221.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Tender Boat	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		HDPE Pipe(12m)	169.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	169.8	0.0	0.0	0.0	0.0
		HDPE Pipe(18m)	147.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	147.3	0.0	0.0	0.0	0.0
		Joint	73.2	0.0	0.0	0.0	0.0	0.0	73.2	0.0	0.0	0.0	0.0	0.0	0.0	73.2	0.0	0.0	0.0
		Float	243.4	0.0	0.0	0.0	0.0	0.0	243.4	0.0	0.0	0.0	0.0	0.0	0.0	243.4	0.0	0.0	0.0
		Subtotal	2,875.3	0.0	0.0	0.0	0.0	0.0	316.6	0.0	0.0	0.0	0.0	2,006.2	317.1	316.6	0.0	0.0	0.0
	Operation and Maintenance cost	Operation	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1
		Maintenance	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
		Subtotal	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6
	Total Cost		2,913.0	37.6	37.6	37.6	37.6	37.6	354.3	37.6	37.6	37.6	37.6	2,043.8	354.7	354.3	37.6	37.6	37.6
	Cumulative Cost (A)		2,913.0	2,950.6	2,988.2	3,025.9	3,063.5	3,101.1	3,455.4	3,493.0	3,530.7	3,568.3	3,605.9	5,649.8	6,004.5	6,358.8	6,396.4	6,434.1	6,471.7

			18-year	19-year	20-year	21-year	22-year	23-year	24-year	25-year	26-year	27-year	28-year	29-year	30-year	31-year	32-year	33-year	34-year
Hydro-Suction System	Equipment Cost	Barge	0.0	0.0	0.0	0.0	0.0	0.0	2,006.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Anchor Handling Boat	0.0	0.0	0.0	0.0	0.0	221.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Tender Boat	0.0	0.0	0.0	0.0	0.0	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		HDPE Pipe(12m)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	169.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		HDPE Pipe(18m)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	147.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Joint	0.0	0.0	0.0	73.2	0.0	0.0	0.0	0.0	0.0	0.0	73.2	0.0	0.0	0.0	0.0	0.0	0.0
		Float	0.0	0.0	0.0	243.4	0.0	0.0	0.0	0.0	0.0	0.0	243.4	0.0	0.0	0.0	0.0	0.0	0.0
		Subtotal	0.0	0.0	0.0	316.6	0.0	235.4	2,006.2	0.0	317.1	0.0	316.6	0.0	0.0	0.0	0.0	0.0	0.0
	Operation and Maintenance cost	Operation	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1
		Maintenance	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
		Subtotal	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6
	Total Cost		37.6	37.6	37.6	354.3	37.6	273.0	2,043.8	37.6	354.7	37.6	354.3	37.6	37.6	37.6	37.6	37.6	37.6
	Cumulative Cost (A)		6,509.3	6,547.0	6,584.6	6,938.9	6,976.5	7,249.5	9,293.3	9,331.0	9,685.7	9,723.4	10,077.6	10,115.3	10,152.9	10,190.5	10,228.2	10,265.8	10,303.4

			35-year	36-year	37-year	38-year	39-year	40-year	41-year	42-year	43-year	44-year	45-year	46-year	47-year	48-year	49-year	50-year	Total
Hydro-Suction System	Equipment Cost	Barge	0.0	2,006.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,006.2	0.0	0.0	10,030.9
		Anchor Handling Boat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	221.5	0.0	0.0	0.0	0.0	664.5
		Tender Boat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.9	0.0	0.0	0.0	0.0	41.6
		HDPE Pipe(12m)	0.0	0.0	0.0	0.0	169.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	679.4
		HDPE Pipe(18m)	0.0	0.0	0.0	0.0	147.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	589.1
		Joint	73.2	0.0	0.0	0.0	0.0	0.0	0.0	73.2	0.0	0.0	0.0	0.0	0.0	0.0	73.2	0.0	585.8
		Float	243.4	0.0	0.0	0.0	0.0	0.0	0.0	243.4	0.0	0.0	0.0	0.0	0.0	0.0	243.4	0.0	1,947.3
		Subtotal	316.6	2,006.2	0.0	0.0	317.1	0.0	0.0	316.6	0.0	0.0	0.0	235.4	0.0	2,006.2	316.6	0.0	14,538.7
	Operation and Maintenance cost	Operation	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	1,756.3
		Maintenance	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	125.4
		Subtotal	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6	1,881.7
	Total Cost		354.3	2,043.8	37.6	37.6	354.7	37.6	37.6	354.3	37.6	37.6	37.6	273.0	37.6	2,043.8	354.3	37.6	16,420.4
	Cumulative Cost (A)		10,657.7	12,701.5	12,739.2	12,776.8	13,131.5	13,169.2	13,206.8	13,561.1	13,598.7	13,636.4	13,674.0	13,947.0	13,984.6	16,028.5	16,382.7	16,420.4	

Source: JICA Study Team

(2) Cost Comparison with Hydraulic Dredging

For comparison the hydro-suction system with the hydraulic dredging system on cost, the cost of the hydraulic dredging system is estimated. The hydraulic dredging system is assumed below in consideration of a scale of dredging amount of 100,000 m^3, and those dredging material is to be flowed downstream through pipeline as well as the hydro-suction system.

a) Dredger ; D600PS Type

b) Pipeline length; 500m

The cost for it also comprises i) Equipment cost, ii) Operation and Maintenance. The equipment cost consists i) Dredger and others, ii) Device. Table 5.2.5 shows the equipment cost and an annual O&M cost of the hydraulic dredging sediment removal system. The cost of hydraulic sediment removal system is also estimated in 11 years and 50 years as well as the case of hydro-suction sediment removal system. The results are shown in Table 5.2.6 and 5.2.7, respectively. Table 5.2.8 shows net present value of them. The currency, exchange rate and discount rate below are adopted as well as the hydro-suction sediment removal system.

a) Currency

U.S. Dollar

b) Exchange rate

US $ 1.0 = Yen119.63

c) Discount rate

A discount rate of 12%

Table 5.2.5 Cost of the Dredger Sediment Removal System

Description	Unit	Quantity	Unit Cost US$	Cost US$, thousand	Remarks
Equipment cost					
Dredger (D600PS)	nr	1	4,208,800	4,209	11-year of service life
Anchor holding Boat	nr	1	222,000	222	22-year of service life
Tender Boat	nr	1	14,000	14	22-year of service life
HDPE Pipe (6m-long)	pcs	77	102,000	102	6-year of service life
Joint	pcs	36	108,000	108	6-year of service life
Float	pcs	35	195,000	195	6-year of service life
Sub Total				4,850	
O&M cost					
Operation cost	unit	1	97,572	97	Suction amount of 100,000m^3
Maintenance cost	unit	1	2,508	3	
Sub Total				100	
Total				4,950	

Source: JICA Study Team

Table 5.2.6 Cost of the Dredger Sediment Removal System in 11 Years

			1-year	2-year	3-year	4-year	5-year	6-year	7-year	8-year	9-year	10-year	11-year	Total
Pumped Dredging System	Equipment Cost	Pumped Dredger	4,208.8	0	0	0	0	0	0	0	0	0	0	4,208.8
		Anchor Handling Boa	221.5	0	0	0	0	0	0	0	0	0	0	221.5
		Tender Boat	13.9	0	0	0	0	0	0	0	0	0	0	13.9
		Steel Pipe	102.3	0	0	0	0	0	102.3	0	0	0	0	204.7
		Joint	107.7	0	0	0	0	0	107.7	0	0	0	0	215.5
		Float	194.9	0	0	0	0	0	194.9	0	0	0	0	389.7
		Subtotal	4,849.1	0	0	0	0	0	404.9	0	0	0	0	5,254.0
	Operation and Maintenance cost	Operation	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	1,073.7
		Maintenance	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	27.6
		Subtotal	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	1,101.3
	Total Cost		4,949.2	100.1	100.1	100.1	100.1	100.1	505.0	100.1	100.1	100.1	100.1	6,355.3
	Cumulative Cost (B)		4,949.2	5,049.4	5,149.5	5,249.6	5,349.7	5,449.8	5,954.9	6,055.0	6,155.1	6,255.2	6,355.3	

Source: JICA Study Team

Table 5.2.8 The Net Present Value of the Dredger Sediment removal System Cost

(Thousand US$)

Description	11-year Period		50- year Period	
	Cost	NPV	Cost	NPV
Equipment Cost	5,254	4,513	24,990	6,128
O&M Cost	1,101	594	5,006	831
Total	6,355	5,107	29,996	6,959

Note : NPV means net present value.

Source: JICA Study Team

The comparison of cost for Hydro-suction system and Hydraulic dredging system is shown in Table 5.2.9. As regards unit cost, Hydro-suction system cost about 3 US$/$m^3$ in 11-year period and about 1 US$/$m^3$ in 50-year period, while they are about 5 US$/$m^3$ and 2 US$/$m^3$ both in 11-year period and 50-year period each for Hydraulic dredging system. There are quite big difference between them both in 11-year period and 50-year period, the hydro-suction system is less 40 % than the hydraulic dredging system.

Table 5.2.9 Comparison of Cost

(Thousand US$)

	Hydro-suction System		Dredger System	
Period	11-year period	50- year period	11-year period	50- year period
Suction Amount	1,100,000m^3	5,000,000m^3	1,100,000m^3	5,000,000m^3
Equipment Cost	2,710 (2.5)	3,629 (0.7)	4,513 (4.1)	6,128 (1.2)
O&M Cost	223 (0.2)	313 (0.06)	594 (0.5)	831 (0.2)
Total	2,933 (2.7)	3,942 (0.8)	5,107 (4.6)	6,959 (1.4)

Note; the parenthetic value shows the cost per unit suction amount (US$/$m^3$)

Source: JICA Study Team

Table 5.2.7 Cost of the Dredger Sediment Removal System in 50 Years

			1-year	2-year	3-year	4-year	5-year	6-year	7-year	8-year	9-year	10-year	11-year	12-year	13-year	14-year	15-year	16-year	17-year
Pumped Dredging System	Equipment Cost	Pumped Dredger	4,208.8	0	0	0	0	0	0	0	0	0	0	4,208.8	0	0	0	0	0
		Anchor Handling Boa	221.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Tender Boat	13.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Steel Pipe	102.3	0	0	0	0	0	102.3	0	0	0	0	0	0	102.3	0	0	0
		Joint	107.7	0	0	0	0	0	107.7	0	0	0	0	0	0	107.7	0	0	0
		Float	194.9	0	0	0	0	0	194.9	0	0	0	0	0	0	194.9	0	0	0
		Subtotal	4,849.1	0	0	0	0	0	404.9	0	0	0	0	4,209	0	404.9	0	0	0
	Operation and Maintenance cost	Operation	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6
		Maintenance	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
		Subtotal	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1
	Total Cost		4,949.2	100.1	100.1	100.1	100.1	100.1	505.0	100.1	100.1	100.1	100.1	4,308.9	100.1	505.0	100.1	100.1	100.1
	Cumulative Cost (B)		4,949.2	5,049.4	5,149.5	5,249.6	5,349.7	5,449.8	5,954.9	6,055.0	6,155.1	6,255.2	6,355.3	10,664.3	10,764.4	11,269.4	11,369.5	11,469.7	11,569.8

			18-year	19-year	20-year	21-year	22-year	23-year	24-year	25-year	26-year	27-year	28-year	29-year	30-year	31-year	32-year	33-year	34-year
Pumped Dredging System	Equipment Cost	Pumped Dredger	0	0	0	0	0	0	4,208.8	0	0	0	0	0	0	0	0	0	0
		Anchor Handling Boa	0	0	0	0	0	221.5	0	0	0	0	0	0	0	0	0	0	0
		Tender Boat	0	0	0	0	0	13.9	0	0	0	0	0	0	0	0	0	0	0
		Steel Pipe	0	0	0	102.3	0	0	0	0	0	0	102.3	0	0	0	0	0	0
		Joint	0	0	0	107.7	0	0	0	0	0	0	107.7	0	0	0	0	0	0
		Float	0	0	0	194.9	0	0	0	0	0	0	194.9	0	0	0	0	0	0
		Subtotal	0	0	0	404.9	0	235.4	4,208.8	0	0	0	404.9	0	0	0	0	0	0
	Operation and Maintenance cost	Operation	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6
		Maintenance	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
		Subtotal	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1
	Total Cost		100.1	100.1	100.1	505.0	100.1	335.5	4,308.9	100.1	100.1	100.1	505.0	100.1	100.1	100.1	100.1	100.1	100.1
	Cumulative Cost (B)		11,669.9	11,770.0	11,870.1	12,375.2	12,475.3	12,810.8	17,119.7	17,219.8	17,320.0	17,420.1	17,925.1	18,025.2	18,125.3	18,225.5	18,325.6	18,425.7	18,525.8

			35-year	36-year	37-year	38-year	39-year	40-year	41-year	42-year	43-year	44-year	45-year	46-year	47-year	48-year	49-year	50-year	Total
Pumped Dredging System	Equipment Cost	Pumped Dredger	0	4,208.8	0	0	0	0	0	0	0	0	0	0	0	4,208.8	0	0	21,044.1
		Anchor Handling Boa	0	0	0	0	0	0	0	0	0	0	0	221.5	0	0	0	0	664.5
		Tender Boat	0	0	0	0	0	0	0	0	0	0	0	13.9	0	0	0	0	41.6
		Steel Pipe	102.3	0	0	0	0	0	0	102.3	0	0	0	0	0	0	102.3	0	818.7
		Joint	107.7	0	0	0	0	0	0	107.7	0	0	0	0	0	0	107.7	0	861.9
		Float	194.9	0	0	0	0	0	0	194.9	0	0	0	0	0	0	194.9	0	1,558.8
		Subtotal	404.9	4,208.8	0	0	0	0	0	404.9	0	0	0	235.4	0	4,208.8	404.9	0	24,989.6
	Operation and Maintenance cost	Operation	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	4,880.5
		Maintenance	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	125.4
		Subtotal	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	5,005.9
	Total Cost		505.0	4,308.9	100.1	100.1	100.1	100.1	100.1	505.0	100.1	100.1	100.1	335.5	100.1	4,308.9	505.0	100.1	29,995.5
	Cumulative Cost (B)		19,030.9	23,339.8	23,439.9	23,540.0	23,640.1	23,740.2	23,840.4	24,345.4	24,445.5	24,545.6	24,645.8	24,981.3	25,081.4	29,390.3	29,895.4	29,995.5	

Source: JICA Study Team

5.3 Maintenance Plan

(1) Optimum Maintenance Plan

It is quite important to keep in good condition for the hydro-suction sediment removal system, which can be operated at low cost for long time. The maintenance is classified in two kinds, a daily maintenance and a regular maintenance. The daily maintenance is done in a simple way whether equipment works or not, or it does not have any damage judging by its appearance. The regular maintenance covers a replacement according to a schedule.

(2) Check Plan

The following checks are done to each equipment before starting as the daily maintenance. (Table5.3.1 shows each requirement and their check points.)

At check, a checklist is to be used to prevent missing.

① Check by its appearance for the body of Siphon Barge, Anchor Handling Boat and Tender Boat, and HDPE Pipe.

② Check of functions by starting and stopping for equipment as pump, generator, etc.

③ Check of the number and availability of Fire Extinguisher, Life-Jacket, etc.

The check plan for the regular maintenance is shown in Table 5.3.2.

Table 5.3.1 Daily Maintenance Plan

Item	Remarks
Siphon Barge	
Body	Damage, Deformation, Crack, Corrosion etc.
Pump	Sound, Vibrations, Damage, Wear etc.
Generator	Sound, Vibrations, Damage, Wear, Corrosion etc.
Electric Equipment	Sound, Vibrations, Damage, Wear, Heat etc.
Winch	Damage, Wear etc.
Excavator	Damage, Wear, Corrosion etc.
Measurement Gauges	Damage, Deformation, Corrosion etc.
Fire Extinguisher	Quantity, Damage, Lifetime, Liquid Leak etc.
Life-Jacket	Quantity, Damage, Wear etc.
Anchor Handling Boat	Damage, Deformation, Crack, Corrosion etc.
Tender Boat	Damage, Deformation, Crack, Corrosion etc.
HDPE Pipe etc.	Damage, Deformation, Wear, Liquid Leak, Corrosion etc.

Source: JICA Study Team

Table 5.3.2 Regular Maintenance Plan

Item	Regular Services	Overhaul	Regular Exchange			Painting	Remarks
	every 2 months	Every 7 years	every 2 years	every 3 years	every 7 years	every year	
Siphon Barge							
Body	○					○	Deck, Outside, Hold
Pump	○	○	○				Shaft, Bearing
Generator	○	○	○				Noise, Vibration, Exhaust gas
Electric Equipment	○		○				Switch, Wiring, Fuse, Distributor, Control board
Winch	○			○			Shaft, Bearing, Wire rope, Brake, Clutch
Excavator	○				○	○	Hydraulic piping
Measurement Gauges	○		○				Pressure gauge, Flow-meter, Density meter

Fire Extinguisher	○				○		
Life-Jacket	○			○			
Anchor Handling Boat	○					○	Body, Winch, Engine, Wire Rope, etc.
Tender Boat	○	○				○	Body, Engine
HDPE Pipe etc.	○				○		Float, Rubber sleeve

Source: JICA Study Team

(3) Repair Plan

To provide against a trouble or an accident, several service stations are chosen and being listed to contact them by phone or e-mail, who can repair it. An immediate repair is to be required as soon as any trouble of equipment being found. To avoid unforeseen circumstances, it is necessary to repair it at the early stage.

(4) Staff Assignment

The required a number of staff for the regular maintenance is roughly estimated and shown below.

① Regular services (every 2 months) : 2 members of staff for 1 day
② Overhaul (every 7 years) : 5 members of staff for 4 days
③ Regular exchange (every 7 years) : 4 members of staff for 4 days
④ Regular exchange (every 3 years) : 4 members of staff for 2 days
⑤ Regular exchange (every 2 years) : 4 members of staff for 4 days
⑥ Painting (every year) : 2 members of staff for 4 days

5.4 Consideration

5.4.1 Combination Plan

It might be a good idea to combine the hydro-suction system with the hydraulic dredging system in consideration of the advantages and disadvantages below.

i) Advantage
① The hydro-suction system is economical on operation.
② The hydraulic dredging system is a sure method and has no restriction on operation time.

ii) Disadvantage
① The hydro-suction system has restriction on operation time because of a sufficient head being used as the energy for dredging.
② The hydraulic dredging system needs fuel to operate.

The combination of the hydro-suction system and the hydraulic dredging system might be desirable in Wonogiri Reservoir, in which, they complement each other.

5.4.2 Feature and Cost

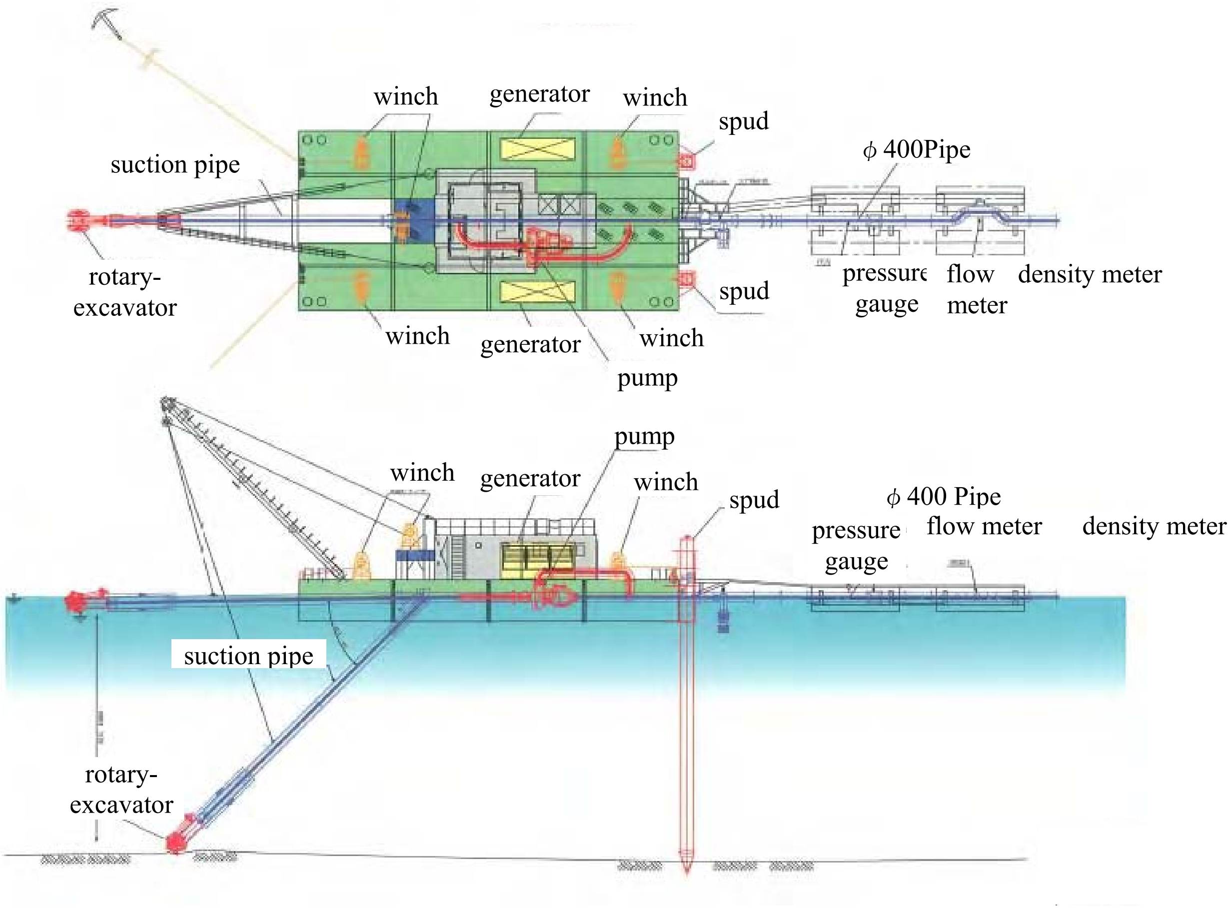
The feature of the combination system is shown in Figure 5.4.1 and its cost is shown in Table 5.4.1 to 5.4.3. This system is aiming at suction amount of 120,000 m^3 (100,000 m^3 for the hydro-suction system and 20,000 m^3 for the dredger system). Table 5.4.4 shows net present value of them.

The currency, exchange rate and discount rate in the hydro-suction sediment removal system are adopted in this system.

Table 5.4.1 Cost of the Combination System

Description	Unit	Quantity	Unit Cost US$	Cost US$,thousand	Remarks
Equipment cost					
Barge	nr	1	2,591,300	2,591	11-year of service life
Anchor Holding Boat	nr	1	222,000	222	22-year of service life
Tender Boat	nr	1	14,000	14	22-year of service life
HDPE Pipe (12m-long)	pcs	56	7,400	415	12-year of service life
HDPE Pipe (18m-long)	pcs	14	8,700	121	12-year of service life
Joint	pcs	56	1,620	91	6-year of service life
Float	pcs	112	3,670	411	6-year of service life
Sub Total				3,865	
O&M cost					
Operation Cost	unit	1	77,000	77	Suction amount of 120,000m^3/year
Maintenance Cost	unit	1	2,500	2.5	Annual Maintenance
Sub Total				79.5	
Total				3,945	

Source: JICA Study Team



Source: JICA Study Team

Figure 5.4.1 Plan and Cross Section of Barge

Table 5.4.2 Cost of the Combination System in 11 Years

(Unit:1000 US$)

			1-year	2-year	3-year	4-year	5-year	6-year	7-year	8-year	9-year	10-year	11-year	Total
Hydro-Suction System	Equipment Cost	Barge	2,591.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,591.3
		Anchor Handling Boat	221.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	221.5
		Tender Boat	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.9
		HDPE Pipe(12m)	414.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	414.7
		HDPE Pipe(18m)	121.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	121.2
		Joint	90.8	0.0	0.0	0.0	0.0	0.0	90.8	0.0	0.0	0.0	0.0	181.6
		Float	411.0	0.0	0.0	0.0	0.0	0.0	411.0	0.0	0.0	0.0	0.0	822.0
		Subtotal	3,864.4	0.0	0.0	0.0	0.0	0.0	501.8	0.0	0.0	0.0	0.0	4,366.3
	Operation and Maintenance cost	Operation	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	846.5
		Maintenance	3	3	3	3	3	3	3	3	3	3	3	27.6
		Subtotal	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	874.1
	Total Cost		3,943.9	79.5	79.5	79.5	79.5	79.5	581.3	79.5	79.5	79.5	79.5	5,240.4
	Cumulative Cost (A)		3,944	4,023.4	4,102.8	4,182.3	4,261.8	4,341.2	4,922.5	5,002.0	5,081.4	5,160.9	5,240.4	

Source: JICA Study Team

Table 5.4.4 The Net Present Value of the Combination System Cost

(Thousand US$)

Description	11-year period		50- year period	
	Cost	NPV	Cost	NPV
Equipment Cost	4,366	3,677 (2.8)	19,821	4,930 (0.8)
O&M cost	874	472 (0.4)	3,973	660 (0.1)
Total	5,240	4,149 (3.2)	23,794	5,590 (0.9)

Note : NPV means net present value.
the parenthetic value shows the cost per unit suction amount (US$/$m^3$)

Source: JICA Study Team

Table 5.4.3 Cost of the Combination System in 50 Years

(Unit:1000 US$)

			1-year	2-year	3-year	4-year	5-year	6-year	7-year	8-year	9-year	10-year	11-year	12-year	13-year	14-year	15-year	16-year	17-year
Hydro-Suction System	Equipment Cost	Barge	2,591.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,591.3	0.0	0.0	0.0	0.0	0.0
		Anchor Handling Boat	221.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Tender Boat	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		HDPE Pipe(12m)	414.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	414.7	0.0	0.0	0.0	0.0
		HDPE Pipe(18m)	121.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	121.2	0.0	0.0	0.0	0.0
		Joint	90.8	0.0	0.0	0.0	0.0	0.0	90.8	0.0	0.0	0.0	0.0	0.0	0.0	90.8	0.0	0.0	0.0
		Float	411.0	0.0	0.0	0.0	0.0	0.0	411.0	0.0	0.0	0.0	0.0	0.0	0.0	411.0	0.0	0.0	0.0
		Subtotal	3,864.4	0.0	0.0	0.0	0.0	0.0	501.8	0.0	0.0	0.0	0.0	2,591.3	535.9	501.8	0.0	0.0	0.0
	Operation and Maintenance cost	Operation	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0
		Maintenance	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		Subtotal	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5
	Total Cost		3,943.9	79.5	79.5	79.5	79.5	79.5	581.3	79.5	79.5	79.5	79.5	2,670.8	615.4	581.3	79.5	79.5	79.5
	Cumulative Cost (A)		3,944	4,023.4	4,102.8	4,182.3	4,261.8	4,341.2	4,922.5	5,002.0	5,081.4	5,160.9	5,240.4	7,911.2	8,526.5	9,107.8	9,187.3	9,266.7	9,346.2

			18-year	19-year	20-year	21-year	22-year	23-year	24-year	25-year	26-year	27-year	28-year	29-year	30-year	31-year	32-year	33-year	34-year
Hydro-Suction System	Equipment Cost	Barge	0.0	0.0	0.0	0.0	0.0	0.0	2,591.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Anchor Handling Boat	0.0	0.0	0.0	0.0	0.0	221.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Tender Boat	0.0	0.0	0.0	0.0	0.0	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		HDPE Pipe(12m)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	414.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		HDPE Pipe(18m)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	121.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Joint	0.0	0.0	0.0	90.8	0.0	0.0	0.0	0.0	0.0	0.0	90.8	0.0	0.0	0.0	0.0	0.0	0.0
		Float	0.0	0.0	0.0	411.0	0.0	0.0	0.0	0.0	0.0	0.0	411.0	0.0	0.0	0.0	0.0	0.0	0.0
		Subtotal	0.0	0.0	0.0	501.8	0.0	235.4	2,591.3	0.0	535.9	0.0	501.8	0.0	0.0	0.0	0.0	0.0	0.0
	Operation and Maintenance cost	Operation	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0
		Maintenance	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		Subtotal	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5
	Total Cost		79.5	79.5	79.5	581.3	79.5	314.9	2,670.8	79.5	615.4	79.5	581.3	79.5	79.5	79.5	79.5	79.5	79.5
	Cumulative Cost (A)		9,425.7	9,505.1	9,584.6	10,165.9	10,245.3	10,560.2	13,231.0	13,310.4	13,925.8	14,005.3	14,586.6	14,666.0	14,745.5	14,825.0	14,904.4	14,983.9	15,063.4

			35-year	36-year	37-year	38-year	39-year	40-year	41-year	42-year	43-year	44-year	45-year	46-year	47-year	48-year	49-year	50-year	Total
Hydro-Suction System	Equipment Cost	Barge	0.0	2,591.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,591.3	0.0	0.0	12,956.6
		Anchor Handling Boat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	221.5	0.0	0.0	0.0	0.0	664.5
		Tender Boat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.9	0.0	0.0	0.0	0.0	41.6
		HDPE Pipe(12m)	0.0	0.0	0.0	0.0	414.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,659.0
		HDPE Pipe(18m)	0.0	0.0	0.0	0.0	121.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	484.7
		Joint	90.8	0.0	0.0	0.0	0.0	0.0	0.0	90.8	0.0	0.0	0.0	0.0	0.0	0.0	90.8	0.0	726.5
		Float	411.0	0.0	0.0	0.0	0.0	0.0	0.0	411.0	0.0	0.0	0.0	0.0	0.0	0.0	411.0	0.0	3,288.0
		Subtotal	501.8	2,591.3	0.0	0.0	535.9	0.0	0.0	501.8	0.0	0.0	0.0	235.4	0.0	2,591.3	501.8	0.0	19,821.0
	Operation and Maintenance cost	Operation	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	3,847.8
		Maintenance	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	125.4
		Subtotal	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	79.5	3,973.2
	Total Cost		581.3	2,670.8	79.5	79.5	615.4	79.5	79.5	581.3	79.5	79.5	79.5	314.9	79.5	2,670.8	581.3	79.5	23,794.2
	Cumulative Cost (A)		15,644.6	18,315.4	18,394.9	18,474.3	19,089.7	19,169.2	19,248.7	19,829.9	19,909.4	19,988.9	20,068.3	20,383.2	20,462.6	23,133.4	23,714.7	23,794.2	

Source: JICA Study Team

Attachment

Details of Cost Estimate

Details of Hydro-suction System

Summary

I t e m	Description	Unit	Quantity	Unit Cost	Quantity	Remarks
Dredging works	1.Siphon dredging	m^3	100,000	0.3	27,310	refer to Table C-1
	Sub total				27,310	
	2.Placement and removal for Float	m	250.0	1.2	300	refer to Table C-2
	3.Placement and removal for Pipeline on the lar	m	250.0	11.0	2,750	refer to Table C-3
	Sub total				3,050	
	4.Tender Boat	set	1	2,494	2,494	refer to Table C-4
Sub total					32,854	①
Site management cost	①×7%				2,300	
Indirect cost					2,300	②
Net cost					35,154	③=①+②
Maintenance cost					2,508	

US$1.00 \119.63

Table C-1 Siphon Dredging (per m^3)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Siphon Barge	Φ600	day	1.0	353	353	refer to Table UC-1
Anchor Handling Boat	D3t 44kw	day	1.0	18	18	refer to Table UC-2
Contingency		%	0.5	371	2	
Total		m^3	1,365.0	0.3	373	unit cost estimate

Table C-2 Cost of Placement and removal for Float (per m)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Anchor Handling Boat	D3t 44kw	day	0.6	18	11	refer to Table UC-2
Crew		person	4.0	16	64	
Contingency		%	0.5	74	0.4	
Total		m	60.0	1.2	75	unit cost estimate

Table C-3 Cost of Placement and removal for Pipeline on the land (Φ600mm L=6m)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Crane	20t suspension	day	1.1	368	405	
Truck	8t carrying	day	0.4	334	134	
Crew		person	7.6	16	121	
Contingency		%	0.5	659	3	
Total		m	60.0	11.0	662	unit cost estimate

Table C-4 Tender Boat (D30 PS3.0t)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Tender Boat	D30 PS3.0t	day	73.0	34	2,482	refer to Table UC-3
Contingency		%	0.5	2,482	12	
Total					2,494	

US$1.00 \119.63

Table UC-1 Siphon Barge Operation (7.0hours/1day)

I t e m	Description	Unit	Quantity	Unit Cost (US$)	Cost (US$)	Remarks
Fuel	Light Oil	L	294.00	0.8	221	42L/h
Captain		person	1.20	24.2	29	
Chief Crew		person	1.20	21.9	26	
Crew		person	4.80	15.9	76	
Total					353	

Table UC-2 Anchor Handling Boat (D3t 44kw) Operation (4.0hours/day)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Fuel	Heavy Oil (A)	L	39.00	0.5	18	

Table UC-3 Tender Boat (D30 PS3.0t) (2.4hours/day)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Fuel	Heavy Oil (A)	L	16.80	0.5	8	※7×2.4
Chief Crew		person	1.20	21.9	26	
Total					34	
Heavy Oil Consumption per kilowatt 0.322(L/h)						
30 × 0.7355 22	PS → KW					
※22 × 0.322 7						

Details of Dredger System

Summary

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Dredging works	1.Hydraulic dredging	m^3	100,000	0.9	89,520	refer to Table C-1
	Sub total				89,520	
	2.Placement and removal for Float	m	250.0	1.2	300	refer to Table C-2
	3.Placement and removal for Pipeline on the lan	m	250.0	11.0	2,750	refer to Table C-3
	Sub total				3,050	
	4.Tender Boat	set	1	2,494	2,494	refert to Table C-4
Sub total					95,064	①
Site management cost					2,508	
Indirect cost					2,508	②
Net cost					97,572	③=①+②
Maintenance cost					2,508	

US$1.00 \119.63

Table C-1 Hydraulic Dredging (per m^3)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Pump dredger	D1,100ps	day	1.0	1,198	1,198	refer to Table UC-1
Anchor Handling Boat	D3t 44kw	day	1.0	18	18	refer to Table UC-2
Contingency		%	0.5	1,216	6	
Total		m^3	1,365.0	**0.9**	1,222	unit cost estimate

Table C-2 Cost of Placement and removal for Float (per m)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Anchor Handling Boat	D3t 44kw	day	0.6	18	11	refer to Table UC-2
Crew		person	4.0	16	64	
Contingency		%	0.5	74	0.4	
Total		m	60.0	**1.2**	75	unit cost estimate

Table C-3 Cost of Placement and removal for Pipeline on the land (Φ560mm L=6m)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Crane	20t suspension	day	1.1	368	405	
Truck	8t carrying	day	0.4	334	134	
Crew		person	7.6	16	121	
Contingency		%	0.5	659	3	
Total		m	60.0	**11.0**	662	unit cost estimate

Table C-4 Tender Boat (D30 PS3.0t)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Tender Boat	D30 PS3.0t	day	73.0	34	2,482	refer to Table UC-3
Contingency		%	0.5	2,482	12	
Total					2,494	

US$1.00 \119.63

Table UC-1 Pump Dredger (1,100ps) Operation (7.0hours/1day)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Fuel	Heavy Oil (A)	L	2,156.00	0.5	1,009	168L/h
Captain		person	1.20	24	29	
Chief Crew		person	1.20	22	26	
Crew		person	8.40	16	133	
Total					1,198	

Table UC-2 Anchor Handling Boat (D3t 44kw) Operation (4.0hours/day)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Fuel	Heavy Oil (A)	L	39.00	0.5	18	
					18	

Table UC-3 Tender Boat (D30 PS3.0t) Operation (2.4hours/day)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Fuel	Heavy Oil (A)	L	16.80	0.5	8	※7×2.4
Chief Crew		person	1.20	21.9	26	
Total					34	
Heavy Oil Consumption per kilowatt 0.322(L/h)						
30 × 0.7355 22	PS → KW					
※22 × 0.322 7						

Details of Combination System

Summary

Item	Description	Unit	Quantity	Unit Cost	Quantity	Remarks
Dredging works	1. Siphon dredging (L500m 798m^3/day)	m^3	100,000.0	0.5	46,729	refer to Table C-1
	2. Pump dredging (L1,000m 861m^3/day)	m^3	20,000.0	0.8	16,350	refer to Table C-1
	Sub total				63,079	
	3.Placement and removal for Float	m	750.0	1.2	936	refer to Table C-2
	4.Placement and removal for Pipeline on the lan	m	250.0	11.0	2,760	refer to Table C-3
	Sub total				3,695	
	5.Tender Boat	set	1.0	5,147	5,147	refer to Table C-4
Sub total					71,922	①
Site management cost	①*7%				5,035	
Indirect cost					5,035	②
Net cost					76,956	③=①+②
Maintenance cost					2,508	

US$1.00 \119.63

Table C-1 Pumped Siphon Dredging (per m^3)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
						L500m 798m^3/day
Siphon	Φ400	day	1.0	353	353	refer to Table UC-1
Anchor Handling Boat	D3t 44kw	day	1.0	18	18	refer to Table UC-2
Contingency		%	0.5	371	2	
Total			798.0	0.5	373	unit cost estimate
						L1,000m 861m^3/day
Pump	D600ps	day	1.0	682	682	refer to Table UC-1
Anchor Handling Boat	D3t吊44kw	day	1.0	18	18	refer to Table UC-2
Contingency		%	0.5	700	4	
Total			861.0	0.8	704	unit cost estimate

Table C-2 Cost of Placement and removal for Float (per m)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Anchor Handling Boat	D3t 44kw	day	0.6	18	11	refer to Table UC-2
Crew		person	4.0	16	64	
Contingency		%	0.5	74	0	
Total		m	60.0	1.2	75	unit cost estimate

Table C-3 Cost of Placement and removal for Pipeline on the land (Φ400mm L=18m)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Crane	20t suspension	day	1.1	368	405	
Truck	8t carrying	day	0.4	334	134	
Crew		person	7.6	16	121	
Contingency		%	0.5	659	3	
Total		m	60.0	11.0	662	unit cost estimate

Table C-4 Tender Boat (D30 PS3.0t)

I t e m	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Tender Boat	D30 PS3.0t	day	150.0	34	5,122	refer to Table UC-3
Contingency		%	0.5	5,122	26	
Total					5,147	

US$1.00 \119.63

Table UC-1 Pumped Siphon Barge Operation (7.0hours/1day)

Item		Description	Unit	Quantity	Unit Cost	Cost	Remarks
Siphon	Fuel	Light Oil	L	294.00	0.8	221	42L/h
	Captain		人	1.20	24.2	29	
	Chief Crew		人	1.20	21.9	26	
	Crew		人	4.80	15.9	76	
	Total					353	
Pump	Fuel	Heavy Oil	L	1176.00	0.5	550	168L/h
	Captain		人	1.20	24.2	29	
	Chief Crew		人	1.20	21.9	26	
	Crew		人	4.80	15.9	76	
	Total					682	

Table UC-2 Anchor Handling Boat (D3t 44kw) Operation (4.0jours/1day)

Item	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Fuel	Heavy Oil	L	39.00	0.5	18	42L/h
					18	

Table UC-3 Tender Boat (D30 PS3.0t) Operation (2.4hours/1day)

Item	Description	Unit	Quantity	Unit Cost	Cost	Remarks
Fuel	Heavy Oil (A)	L	16.80	0	8	※7×2.4
Chief Crew		person	1.20	22	26	
Total					34	
Heavy Oil Consumption per kilowatt 0.322(L/h)						
30 × 0.7355 22	PS → KW					
※22 × 0.322 7						