The Study on Comprehensive Disaster Prevention around Mayon Volcano

SUPPORTING REPORT (2)

(Part II : Feasibility Study)

XVI : Facility Design

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1. ADOPTION OF CSG METHOD TO SABO STRUCTURES

1.1 Description of CSG Method

This report recommends a CSG method (the Cemented Sand and Gravel method) for Sabo structures on the Mayon Volcano. The reasons are as follows:

- Since the construction is on a large-scale with wide construction yard, CSG is suitable to the roller compact method.
- The construction site is abundant in good materials available there.
- The strength of the soil used in the existing installations can be improved.

(1) Summary of CSG Method

The CSG method has been developed in order to construct fill dams more economically and effectively by utilizing the materials in the sites or in the vicinity of the dam sites.

The CSG method can make fill dams stronger by improving materials. In order to improve embankment materials such as sands and gravel in the riverbed, cements are added and then both the cements and the materials are mixed together

After the cements and the fill dam materials are mixed at the construction site, the mixtures will be transported by dump trucks or other vehicles. Then the mixtures would be spread by bulldozers and rolled by vibrating rollers to improve embankments. There are other roller compacting methods as follows:.

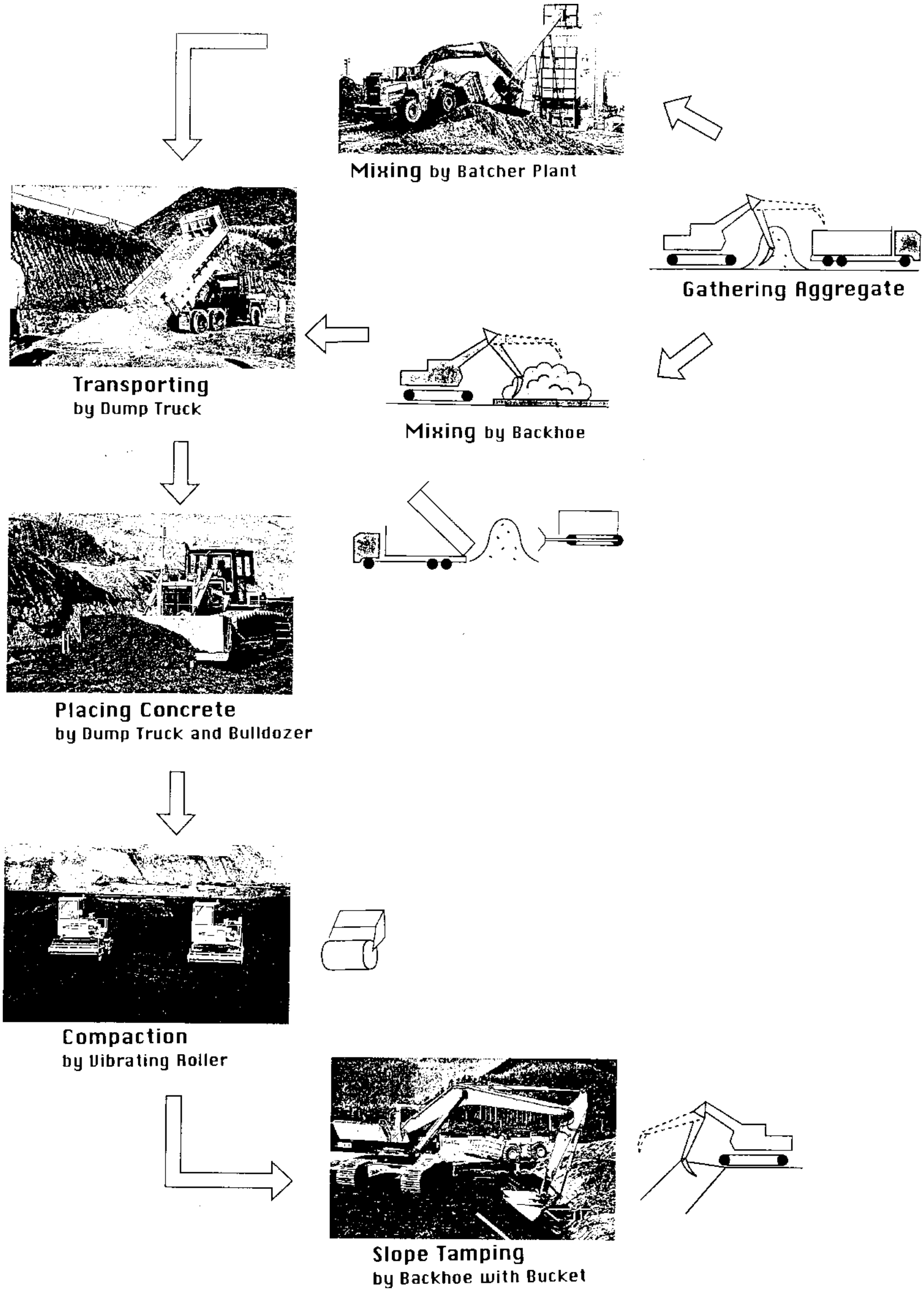
Description of Roller Compacting Methods

	Soil Cement	CSG	INSEM	RCC	RCD
Goals of Development	Foundation Improvement	Simplification of Fill Dam	Effective Utilizing of Materials Available at Construction Site	Rationalization of Dam Construction	Rationalization of Dam Construction
Materials s/a <4.75mm	Flabby Foundation, Clay	With no Grade Processing Eliminate over 80~150mm		Material with Adjusted Grade s/a20~60%	s/a30~35%
Volume of Cement		60~160	70~160	120	
Strength, Mpa		1.5~3	1.5~3	16	16

Notes:
- s/a: Fine aggregate ratio: a ratio of fine materials of 4.75mm in diameter and under to whole grains.

  Mpa＝MN/m^2

  9.8MN/m^2＝100kg/cm^2
- Soil cements are mainly utilized to improve the foundations.
- Materials with even grade aggregates constructed by the RCC method or the RCD method can expect to exert the same strength as a normal concrete.
- Through the RCD method, construction joint, bonding, curing and et al. should be done thoroughly under strict supervising and management.
- The INSEM method is preferable for small-size structures in mountain streams.



Construction Procedure for CSG Method

(2) Characteristics of CSG Method

The characteristics of the CSG method are as follows:

- Effective utilization of the materials which can be obtained in construction sites.
- Intensification of the materials by the CSG method stronger than those of fill dams. It is possible to construct a structure with steep slope gradient.
- Construction of the CSG method is almost the same as that of fill dams. However, compared to soil core frame structures, this method can shorten the completion date, because materials made by the CSG method are water-resistant.
- More economical and effective constructions by utilizing characteristics of the topography, geology and materials of the site.
- It is necessary to construct cutoff zones, because CSG does not set a cutoff condition completely.

Therefore, the CSG method is effective for large-scale structures with conditions that there are plenty of materials in the construction site, that construction yards are wide, and that the cutoff condition will not cause serious problems.

As for stability of structures while designing, we will examine both the concrete gravity dam and the fill dam.

(3) Actual Achievements for CSG Method

The CSG method is already adopted as below : In the temporary cofferdam of upstream fill dam, and in the wing of sabo dam in the Unzen-Mizunashi River. Also, in the consolidation work in the Sacobia River at the Pinatubo Volcano in the Republic of the Philippines, the CLG method, the Cemented Lahar Gravel method, is adopted.

Compared to the CLG method, work volume of this Study which is 450,000-500,000m^3 is larger than that of the CLG method.

Typical Constructions for CSG Method

Name		Location		Year	Hight Overflow (m)	Hight non-over (m)	Length (m)	Crown Width (m)	Slope	Volume (m^3)
Nagashima	Cofferdam	Japan	Shizuoka	1992	14.9		86.5	5.0	0.8	30,000
Chubetsu	Cofferdam	Japan	Hokkaido	1994	4.0		60(281)	5.0	1.2	2,500
Kubusu	Cofferdam	Japan	Toyama	1994	9.0	12.0	87.5	4.0	1.2	13,650
Surikami	Retaing wall	Japan	Fukushima	1996	(21.0)	23.5	120.0	5.0	1.0	14,500
Mizunashi 1	Sabo dam wing R	Japan	Nagasaki	1995	(14.9)	10-20	270.0	5.0	1.2	40,000
	Sabo dam wing L		Nagasaki	-1996	(14.9)	10-20	280.0	5.0	1.2	110,000
Mizunashi 2	Sabo dam wing R	Japan		1997	(14.5)	5-12	230.0	5.0	1.2	25,000
Maskup	Consolidation dam	Philippine	Panpanga	1997?	6.5	8.2	494.0	5.0	2.0	
CLG: Cemented Lahar Gravel										

(4) Characteristics of Materials for CSG Method

The material used in the CSG method vary greatly as the following table indicates. The riverbed materials in the Mayon Volcano and the characteristics of Lahar deposits are effective as the materials of CSG. Also, these materials have good features for CSG as below :

- The specific gravity of Lahar deposits is as large as around 2.65.
- The grade distribution of Lahar deposits is that there are little clay under 0.075mm in diameter, and the fine aggregate ratio (s/a) is from 30 to 45. Therefore, the Lahar deposits show the grade distribution which is near the standard aggregate of the RCD method. In this case, zero slump concrete is used.

Characteristics of Materials for CSG Method

	Nagashima	Chubetsu	Kubusu	Surikami	Mizunashi	Maskup
	River bed material			Volcanic material		
<4.75mm s/a (%)	20-40	30	14-38	40-50	60	95-99
<0.075mm	0	0	0	5-8	5-10	3-17
Uniformity coefficient Uc	12-19		78		17-37	
Specific gravity	2.6	2.6	2.60-2.66	2.3-2.4	2.3-2.4	1.96-2.41
Absorption (%)	1	1	0.9-2.1	11	4-10	5-13
Moisture ratio (%)	5-7	5-8	4-7	15-18	5-12	
Cohesion c	0.33	0.71	1.4	1.3	0.35-0.75	
Internal friction angle ϕ	42	45	42	43.5	41-44	

Characteristics of Materials for CSG Method in Mayon Volcano

Basin	Sieve Analysis		Specific	Density	s/a (%)<80mm	
	d50 (mm)	d90 (mm)	Gravity	Test (g/cc)	Type A (%)	Type B (%)
Yawa	96.75	170.25			33 - 38	
Pawa Burabod	344.00	486.00	2.658	2.364	27 - 49	93
Budiao	73.60	276.40			18 - 42	61
Anoling	189.20	266.00	2.712	2.384	34 - 51	
Average	175.89	299.66	2.685	2.374	28 - 45	77
Lahar					50 - 65	80 - 90

(5) Construction Procedures for CSG Method

The construction procedure of CSG method consists of extracting materials, mixing, transporting, placing, and compaction. The only difference in adopting the CSG method this time from the previous constructions is that in mixing we use either backhoe or plant as indicated in following table. In a large amount of construction, a plant is generally preferred. Also, as the table shows, by using plant, we can increase the amount of construction per day.

Description of Construction by CSG Method

	Nagashima	Chubetsu	Kubusu	Surikami	Mizunashi	Maskup	
Cement	Portland blast fumace cement Type B	Portland cement	Portland blast fumace cement Type B	Portland cement	Portland blast fumace cement Type B	Portland cement	
Cement content	80	60	60	60	80	80	140?
						4.7%	8%
Water content		5-8	4-7	16-20	8-12		
Mixing	Backhoe 0.6m^3	Backhoe	Belt conveyor	Backhoe	Bucher x 2		
Transporting	11t Dump truck	Dump truck	Dump truck	11t Dump truck	8t Drump truck		
Placing	21t Bulldozer 17cm x 3	10t Bulldozer 25cm x 2	16-21t Bulldozer 25cm x 2	10t Bulldozer 25cm x 2	16t Bulldozer 25cm x 2		
Compaction	8t Vibrating Roller	10t Vibrating Roller	8t Vibrating Roller	10t Vibrating Roller	7-10t Vibrating Roller		
time	6	6	6	8	6		
Compressive Strength	2.0-3.0	2.0-3.0	2.0-4.5	1.5-3.0	3.0-1.7	2.7-3.1	6.8-8.4
average		2.2	3.3		6.0	2.94	7.63
Volume m^3/day	400-600	500	500	400-500	1500-2000		

Unit of compressive strength: Mpa $10^6 N/m^2 = N/mm^2$

(6) The Reasons for Adopting CSG Method to Yawa River Project

We have decided to adopt the CSG method to the Yawa River project for the following reasons:

- The construction scale is big (450,000-500,000m^3 in CSG amount) and is suitable for the construction using large construction machines and vehicles.
- There are a large amount of materials which can be obtained in the construction sites.
- The wide construction yard is suitable for the roller compact method.
- The characteristics of the materials will assure desirable structural strength.
- Existing Sabo dam facility which is made by concrete tends to be destroyed because of scouring or piping. But, if the width of dam body is enough, the structures built by the CSG method are less prone to be destroyed than those concrete structures.
- Also, in the case of insufficient width and with little maintenance and operation, the conventional training dike, whose soil is packed materials and which has 1.0m depth of embankment, was destroyed due to gravel bump and runoff of packed soil by scouring. In such a case, if CSG is adapted to the packed materials, it is possible to reduce maintenance and operation because the strength of the materials increases.

1.2 Construction Sequence of CSG Method

(1) Description of Cement and Composition of CSG Method

In Japan, Portland blast furnace slag cement type - B is used due to the market situation. This type of cement is low in exothermic amount, and has no problem in resistance to chemical reaction and in controlling alkaline aggregates reaction.

From previous cases, the amount of the cement needed is estimated to be around 80kg/m^3 , and the moisture ratio to be around 10%. But composition varies according to materials, so confirmation by experiment is necessary.

The composition of CLG (Cemented Lahar and Gravel) used in Pinatubo Volcano is as follows:

Composition and Strength of CLG

	Minimum Cement Content per m^3 kg (bag*)	Maximum Water/Cement Ratio kg/kg	Designated Size of Coarse Aggregate Square Opening Std. mm	Minimum Compressive Strength of 150 x 300mm concrete cylinder specimen at 28 days, MN/m^2(psi)
Cemented Lahar and Gravel (CLG)	80 (2 bags)	2.43	Maximum 150mm	3.5 (508)

* Based on 40 kg/bag
Water content after mixing shall be between 8% and 12%, and minimum dry density shall be 1.85 tf/m^3.

(2) Mixing by Batcher Plant of Cemented Sand and Gravel

Two types of mixing are feasible : backhoe mixing and batcher plant mixing.

In a large scale construction, plant mixing has more advantages than backhoe mixing, because plant mixing has good construction strength, and thereby is more economical.

Backhoe mixing is inferior to plant mixing in that it is weak in quality control and has less strength.

However, in case of doing mixing in the smaller yard, those problems of backhoe mixing can be solved and backhoe mixing is more economical.

(3) Transportation of Cemented Sand and Gravel

CSG should be transported quickly by dump trucks to the site to prevent segregation. If the construction site is far from the mixing yard, the water in CSG would evaporate. In CSG method, management of water content in percent of total weight is most important. So, in transporting, it is necessary to be careful of water evaporation.

(4) Placing Concrete by Dump Truck and Bulldozer for Cemented Sand and Gravel

The placing of CSG transported by the dump truck is done by bulldozers.

Previous cases indicate that 50cm- compaction with two 25cm-thick layers is desirable.

(5) Compaction of Cemented Sand and Gravel

Self-propelled vibrating roller for soil materials is used for CSG compaction.

The compaction mechanism by vibrating roller is considered as the compaction of rolling from the empty weight of the vibrating roller and the fluidity of mortar from abrasion loss among aggregate by the vibration of vibrating roller.

The roll frequency of vibrating roller is estimated by observing the nearly no subsidence of roller and the emergent of cement paste on CSG surface.

Since the result of compaction will vary greatly according to the soil,composition,compaction machine, and construction method, in the actual construction, a test construction is necessary before the work in order to determine the depth of compaction and the most appropriate rolling frequency, etc. based on the construction machine.

(6) Edge Treatment

Land grading is implemented after passing the CSG on 3 or 4 times with bucket of the backhoe. As for the construction method, two-layer land grading with good roll is desirable from the experience of sabo dam construction in the Mizunashi River.

(7) Treatment of construction joint, expansion joint and curing

In case of resuming placing or pouring after a long interruption, it is necessary to clear the placing or pouring surface to remove waste or stagnant water and keep the wetness.

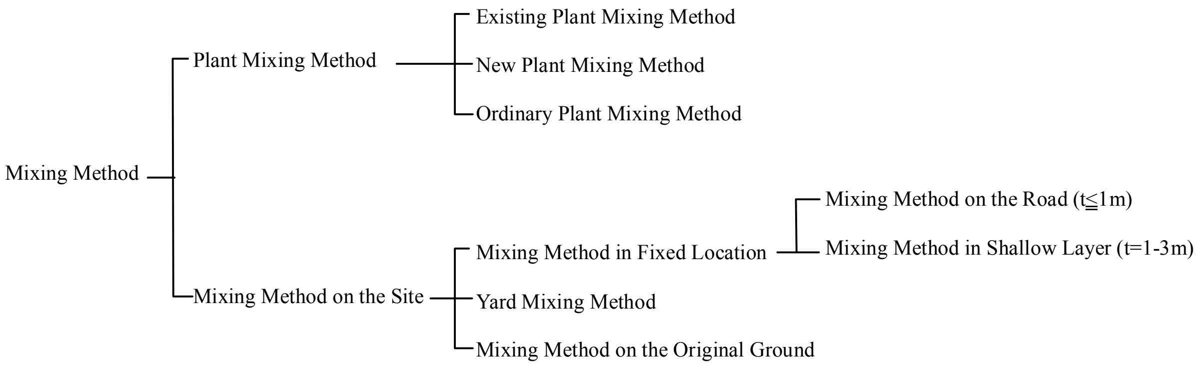
After depositing CSG, appropriate curing is necessary. Especially when insulation is so strong that CSG might dry up, just after compaction curing such as covering the CSG surface with seats is necessary.

(8) Manegement in case of Constructions

The management of CSG is implemented by observing the moisture ratio, unconfined compression strength, and dry density of the concrete cylinder.

1.3 Discussion for Mixing Method and CSG Method

The mixing methods for improving foundation by using cement and the materials which can be obtained at the construction sites are divided into two types as below. Taking economical and construction efficiency into consideration, in the CSG mixing at the Mayon Volcano, plant mixing method or backhoe mixing method would be suitable.



Classification of Mixing Method

The characteristics of each mixing method are as below :

(1) Plant Mixing Method

In plant mixing method, cement, the materials which can be obtained in construction sites, water, and so on are mixed in the placed plant according to the designated composition ratio. This method is suitable for a large scale structures and the quality after mixing is high in reliability. The accuracy of plant mixing method is high in general, but when the materials which can be obtained in construction sites contain much silt and clay, mortar sometimes sticks to the drum and the fan in the mixer, or big coarse aggregate might be discrete. Also, plant mixing method is suitable for large scale construction regarding its economical efficiency, so at present it is difficult to apply this method to middle-scale sabo works.

Taking into consideration that, as real economical efficiency for the new plant, the amount of placing or pouring is more than 30,000-50,000m^3 , the adoption of a new plant is limited to the case such as setting a large scale installation or more than one sabo installations. Therefore, in this plan which needs about 50,000m^3 CSG just for the Yawa River, there exists a good reason for adopting a new plant.

(2) Mixed Methods of Backhoe

Backhoe mixing method is meant by two methods.

① one in which materials are directly mixed at the construction yard.

② one in which materials are mixed at the mixing yard apart from the construction site and then transported to the construction site.

The method ① is more often adopted due to its convenience. However, since this method has several problems as follows, we recommend the method ②.

- In mixing at the construction yard, it is difficult to measure the materials and the dispersion of the amount of cement mixed is large.
- In mixing at the construction yard, there exists a risk to do damage to the embankment surface of existing facilities and thereby the embankment is prone to have weak structure.
- Since almost all the work is done intensively at the construction site, not only is quick construction difficult but it is also necessary to dispose many workers and a lot of machines and vehicles at the relatively narrow construction yard. In our field investigation we adopted backhoe mixing (mixing yard method), for the CSG mixing method and the result of mixing was generally good. It is recorded that the work-hour of mixing with this method was around one minute per $1m^3$.

(3) Comparison of Mixed Methods of Backhoe and others

The comparison of each mixing method is as follows, and as for the construction in the Yawa River we consider mixing by mixer as more economical.

Finally, since homogeneous quality of CSG is expected, we recommend the mixer mixing as the mixing method for the construction in the Yawa River.

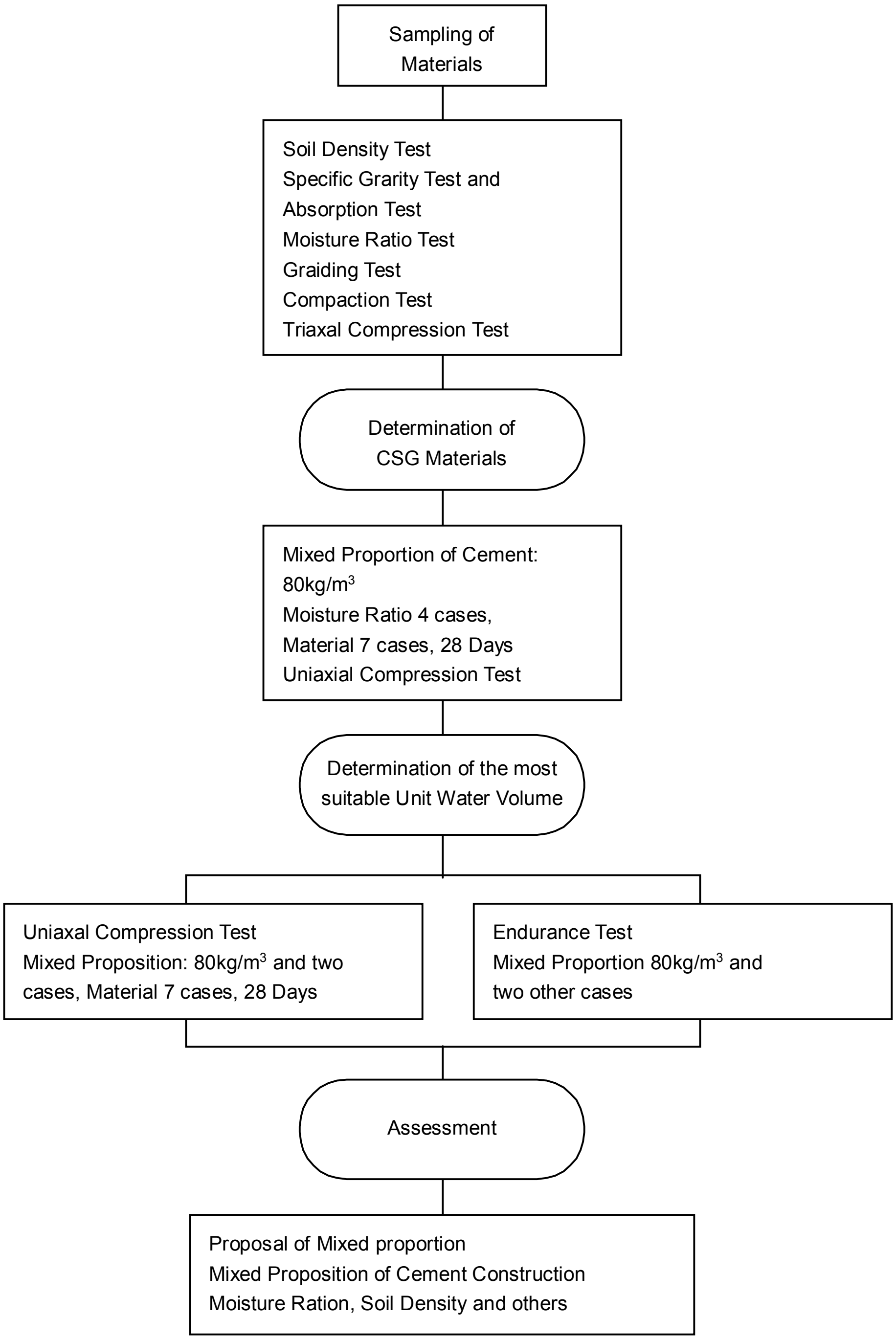
Comparison of Mixing Methods of Backhoe and Others

Cement Mixing Methods			Backhoe Mixing		Mixer Mixing
Construction Condition		Construction Volume (m^3)	500000		
		Construction Volume per day (m^3)	2000		
Standard		(m^3)	0.6	1.2	3.0
Ability of Construction Machine and Required Number	Mixing	Construction Ability (m^3/hr•Vehicle)	60	120	162
		(m^3/day•Vehicle)	420	840	1134
		Required Number (Vehicle•Machine)	5	3	2
			(420×5=2100)	(840×3=2520)	(1134×2=2268)
	Loading	Construction Ability (m^3/hr•Vehicle)	35	70	
		(m^3/day•Vehicle)	245	490	
		Number of Required Vehicles (Vehicle•Machine)	9	5	
			(245×9=2205)	(490×5=2450)	
		Summation (Vehicle•Machine)	14	8	2
Number of Men Required (Men/day)			42	24	18
Construction Cost	Running Cost (Yen/m^3)		5400	5400	4800
	Cost of Assembling Scrapping and Transporting	(Yen/Vehicle)	100000	100000	10000000
		(Vehicle)	14	8	2
		(Yen)	1400000	800000	20000000
		(Yen/m^3)	2.8	1.6	40.0
	Direct Construction Cost (Yen)		5403	5402	4840

1.4 Sampling Test for CSG Method

(1) Laboratory Investigation

The CSG method uses the materials which can be obtained in construction sites. In the first place, laboratory investigation is to be done as is indicated in the chart below.



Flow Diagram of Laboratory Test for CSG Composition

The items and contents of laboratory investigation are indicated in the figure below.

Content of Laboratory Investigation

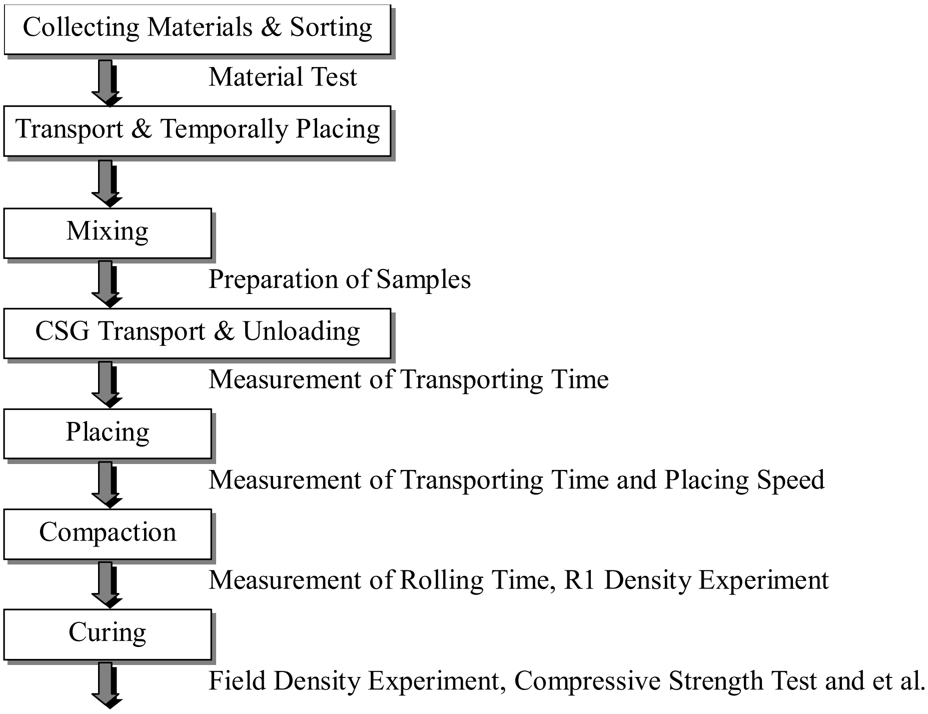
Item	Content
Test of Materials	Identify the quality of the materials obtained upstream of Sabo dam and aggregate bought, by physical and dynamics tests.
Determining CSG Materials	Determine whether the materials are good for CSG.　Firstly, add cement to the materials, which can be obtained in construction sites, and mix. Then, conduct physical and dynamics tests.
Test of the CSG Quality	By quality tests for Strength、Percolation、Endurance, determine the CSG composition ratio indoors and examine the relation to moisture ration, then suggest the standard values for management.

(2) Field Investigation (Experimental Construction)

After identifying the quality of the materials by laboratory investigation and setting the moisture ratio and the amount of cement, field investigation (test construction) is needed. The purposes of this investigation are as follows :

- Confirmation or correction of the basic composition determined by laboratory investigation,
- Command the property of CSG during mixing and after solidification,
- Determination of the construction method, and
- Proposal of the standards and the method of management.

The procedure of the field investigation (test construction) is as follows:



Construction Procedure of Field Investigation

1.5 Comparison between INSEM Method and CSG Method

The INSEM method is suitable for the construction in the mountain stream where the construction yard is small and the processing of the materials which can be obtained in construction sites is difficult. With this method, wastes can be processed within the construction yard. This method is basically the same as the CGS method, but construction scale can be small.

The INSEM method tries to make a series of construction process, from adding cement to soil, to compaction in the thin layer, and to anchorage simply and economically by using just earthmoving machines. Therefore, the idea of the INSEM method differs from the ideas of this plan in that this plan is a big scale works with a large construction yard and plans to exploit the materials and wastes other than soil produced by the work.

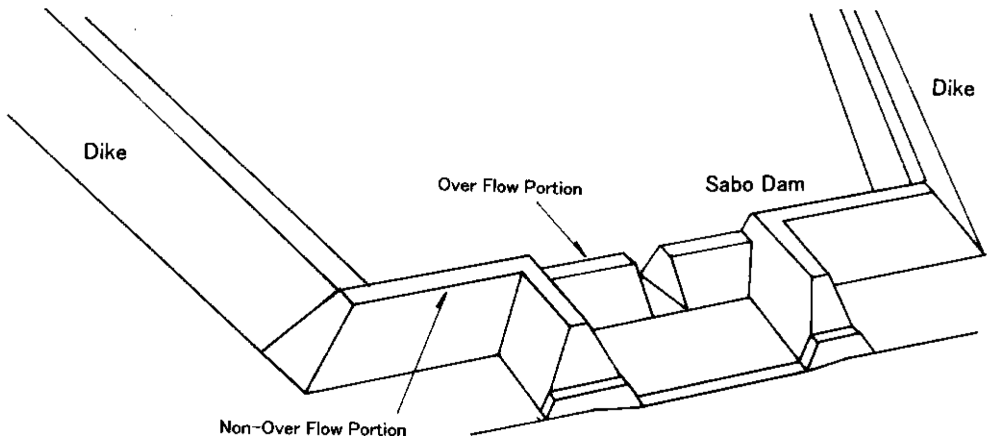
Comparison between INSEM Method and CSG Method

	CSG	INSEM	RCD Concrete
Basic Concept	Originally developed for Temporary Coffer Dam : in order to reduce the cross section of fill dam, by mixing cement and the materials which can be obtained at the construction site, C and Φ are improved. Through the constructions such as Unzen sabo dam, Fujigawa sabo dam, the focus has been on the use of low quality concrete.	Developed in order to exploit all the sediment yield at the construction site and thereby to eliminate transporting sediment. Discussed by Rokko Kouji Jimusho.	Placing and rolling ultra self-consistency concrete to streamline dam construction method. Originally developed in Japan in order to make RCC concrete as strong as ordinary concrete.
Idea of Strength	1) The conception of the fill dam : Temporary coffer dam focusing on improving C and Φ, 2) The conception of the concrete dam : Mainly focusing on the compression strength (e.g., constructions at Unzen and Fujigawa sites)	The conception of the concrete dam: The compression strength of the dam body is great. The compression strength of the apron foundation and leave buffer is improved. During the construction, the compression strength is at the middle level.	The conception of the concrete dam: Mainly focusing on the compression strength
Unconfined Compression Strength Goal C N/mm^2	Unzen : 3.0 Fujigawa : 6.0	About 1.5-4.0	18
Grain Size	No Grain Disposal Cut OFF: 150mm	No Grain Disposal Cut OFF: 80mm	Grain Adjustment
	From our experiences, Fine Aggregate Ratio (s/a) of 30 to 40% is desirable	Gravel and/or disintegrated granite from weathered granite in Mt. Rokko. Fine Aggregate Ratio (s/a) is around 50%.	
Construction Method	The construction methods of CSG and INSEM are basically the same: Placing and rolling self-consistency concrete. Processing the construction joints, joint cutting and curing are not done basically.		Construction Joint, Joint Cutting, Curing
Volume of Cement (kg/m^3)	Temporary Coffer Dam: 60-80 Mizunashigawa Sabo Dam: 80 Fujigawa: 100-160	Stepped Apron Foundation: 70-100 Leeve Filling: 100-130 INSEM Dam: 130-160	
Earthmoving Machine	Large earthmoving machines for streamlined construction	Small earthmoving machines for sabo construction site	Large earthmoving machines for streamlined construction
Mixing	Mixer, Badkhoe	Badkhoe	Plant
Transporting	Dump Truck	Dump Truck	Dump Truck
Placing	Bulldozer	Bulldozer, Badkhoe	
Compaction	Vibrating Roller	Vibrating Roller	Vibrating Roller

2. SAND POCKETING WORKS

2.1 Construction of Structural Components

Sand pocketing consists of the sabo dam which traps and accumulates the debris flow and the training dike which lead the debris flow to the sabo dam.



Sketch of Sand Pocket Facility Component

2.2 Sabo Dam

(1) Types of Sabo Dam

Having compared between concrete gravity dam and the dam using CSG as internal concrete, we have decided to adopt CSG dam mainly due to its economical efficiency and the advantage of exploiting the materials which can be obtained in construction sites.

Comparison between Concrete Dam and CSG Dam

Item	Concrete		Cemented Sand and Gravel	
	Effective Height: 4.0m, Height: 7.0m Length of Apron: 22.5m Upstream Slope 1:0.4 Downstream Slope 1:0.2		Effective Height: 4.0m, Height: 6.0m Cutoff: 1.0m, Length of Apron: 23.5m Upstream Slope 1:1.2 Downstream Slope 1:2.0	
Volume (m^3/m)	Body	35.7	Concrete facing	27.8
	Apron	35.1	Apron	14.3
	Vertical wall	7.5	Vertical wall	5.4
			CSG	66.8
Cost per m	Body	89,250	Concrete facing	69,500
	Apron	87,750	Apron	35,750
	Vertical wall	18,750	Vertical wall	13,500
			CSG	26,720
	Cost (peso/m)	**198,250**	Cost (peso)	**145,984**
	△		○	
Simplicity of Construction	△		○	
Local Supplement	△		○	
Total Decision	△		○	
Unit Price (peso/m^3)	Concrete	2,500	CSG	400

Notes: ○ Good, △ Average, × Failure

Comparison is done about the Anoling Right Sabo dam.

The height of dam body appears low due to the wide dam body of CSG and its cutoff.

(2) Structural Details

1) Dimentions of Dams

The representative values of each dam is shown as below and the Front view is illustrated in the following Figure.

Dimensions of Dams

Dam Name	Dam Height (m)	Dam Length (m)	Crown Width (m)	Waterway Width (m)
Pawa Sabo Dam	6.0	450.0	5.0	55.0
Anoling L Sabo Dam	6.0	375.0	5.0	50.0
Anoling R Sabo Dam	6.0	300.0	5.0	70.0

2) Design Discharge

The design discharge of each installations is as below :

Representative Values of Design Discharges

		A (km^2)	R-day (mm)	f	re (mm/hr)	Q 1/3.6*re*A (m^3/s)	Qps $C_*/(C_*-Cd)$*Q (m^3/s)	a	Qp a*Q (m^3/s)
Pawa-burabod	Sabo Dam	7.5	463	0.7	102.7	214	428	0.5	321
	Training Dike	7.6	463	0.7	102.5	216		0.1	238
Anolong L	Sabo Dam	6.6	458	0.7	103.1	189	378	0.5	284
	Training Dike	7.4	458	0.7	101.5	209		0.1	230
Anoling R	Sabo Dam	8.7	458	0.7	99.4	240	480	0.5	360
	Training Dike	9.3	458	0.7	98.5	254		0.1	279
Anoling D	Training Dike	16.9	458	0.7	91.0	427		0.1	470

Rainfall intensity

Rainfall intensity is calculated according to the method for rainfall intensity in the Technical Instruction (draft) for the measure of debris flow.

$$re = \left(\frac{r24}{24}\right)^{1.21} \cdot \left(\frac{24f^2}{C/60 \cdot A^{0.22}}\right)^{0.606}$$

Where r_{24} : Daily Rainfall (A twenty year return period)

f : Coefficient of Runoff f=0.7

C : Coefficient C=80, which coincides with discharge in downstream

Normal Value: 60~180

A : Catchment Area

Pure Water Discharge

$$Qp = \frac{1}{3.6} \cdot re \cdot A\,(m^3/s)$$

Flood Discharge

According to the Technical Instruction (draft) for the measure of debris flow, flood discharge is to be 1.5 times as big as pure water discharge, taking soil content into consideration.

$Qp' = 1.5 \times Qp$

Peak Discharge of Debris Flow

$$Qsp = \frac{C_*}{C_* - Cd}$$

Where C_* : Bulk Deposition Concentration of Silted Deposition C_* $= 0.6$

Cd : Bulk Deposition Concentration of Debris Flow during Moving: $Cd \geqq 0.3$

$$Cd = \frac{\rho \cdot \tan\theta}{(\sigma - \rho)(\tan\sigma - \tan\theta)} = \frac{1.2 \cdot \tan 6.84°}{(2.60 - 1.20)(\tan 30° - \tan 6.84°)}$$

σ : Density of Gravel $\sigma = 2.60 t/m^3$

ρ : Density of Water $\rho = 1.20 t/m^3$

ϕ : Internal Friction Angle of Silted Deposition $\phi = 30°$

θ : Gradient of Bed Slope

3) Watereway

The waterway dimensions of each installation are as follows:

Waterway Dimensions of Installations

		Discharge	Width of waterway	Slope of waterway	Overflow depth	Allowable height	Height of waterway
Pawa-burabod	Sabo Dam	321	55.0	1.2	2.19	0.80	3.00
Anoling L	Sabo Dam	284	50.0	1.2	2.15	0.80	3.00
Anoling R	Sabo Dam	360	70.0	1.2	2.02	0.90	3.00

Allowable height is to be 0.8m.

The overflow depth is calculated with Seki's Formula in case of flood.

$$Q = \frac{2}{15} \cdot C(2 \cdot g)^{1/2}(3 \cdot B1 + 2 \cdot B2)h_3^{3/2}$$

Where Q : Flood Discharge $Qp' = 1.5 \times Qp$

C : Coefficient of Discharge $C = 0.6$

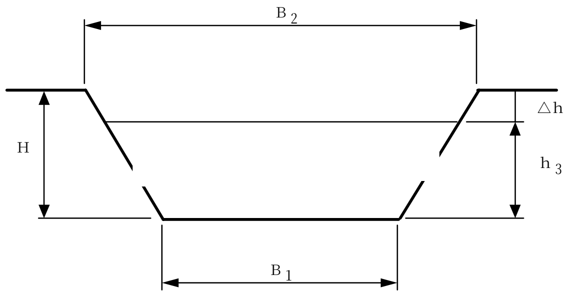
g : Acceleration of Gravity $g = 9.8 m/s^2$

B1 : Waterway Depth B1

Waterway Depth is set as wide as possible taking Flow depth of Debris flow into consideration.

B2 : Overflow Width (m)

h3 : Overflow Depth (m)



Waterway Form

NB : Waterway Height＞Debris Flow Depth.

4) Slit

In order to prevent lowering of the downstream riverbed by flood, and overflowing of debris flow by trench fluctuation, a slit is to be adopted. In a small flood, a slit can lead debris flow to the sabo dam by preventing downstream riverbed from lowering, and by fixing trench. Also with afflux, the flowing soil from bed-load transport and traction can be controlled.

The configuration of the slit is given in the chart below. We propose these slit configuration in order to secure enough scale to let the discharge of the two-year return period flow, and to let afflux exert adjustment effects. Reexamination of the details is necessary at the stage of detailed design.

Dam name	Slit Height (m)	Slit Width (m)	Number	Total Width
Pawa Sabo dam	4.0	5.0	x 2	10.0m
Anoling L Sabo dam	4.0	4.0	x 2	8.0m
Anoling R Sabo dam	4.0	4.0	x 3	12.0m

(3) Dam Body, Cut off and Downstream Apron

1) Main Body Section

Main body section is designed as follows, so that CSG may be constructed with non-formwork.

- Crown Depth: 5.0m (due to the width of Construction Machine)
- Slope Gradient: 1:1.2 (due to the slope grading and construction feature of compaction) Downstream slope gradient is generally 1:0.2, a steep gradient, but in this plan erosion protection using boulders at gentle gradient is necessary due to the non-framework construction method. Also, the downstream slope gradient is to be 1:2.0 from the experiences

of consolidation work in downstream regarding gentle gradient installations.

The results of stability analysis are as follows:

As the stability analysis indicates, by securing enough width of the dam body, subgrade reaction of foundation in downstream can be reduced, which is an advantage for the loose foundation of sand and gravel with small bearing capacity.

Results of Stability Analysis

Item	Safe factor	Pawa Sabo Dam		Anoling L Sabo Dam		Anoling R Sabo Dam	
		Calculation	Decision	Calculation	Decision	Calculation	Decision
Flood Case							
Sliding Fs	1,200	3,278	OK	3,278	OK	3,318	OK
Ecentric distance e	3,233	1,048	OK	1,048	OK	1,041	OK
down σD	30,000	13,960	OK	13,960	OK	13,837	OK
upper σU	30,000	7,126	OK	7,126	OK	7,097	OK
			OK		OK		OK
Debris flow case							
Sliding Fs	1,200	4,012	OK	3,746	OK	3,762	OK
Ecentric distance e	3,233	1,295	OK	1,287	OK	1,295	OK
down σD	30,000	13,445	OK	13,524	OK	13,559	OK
upper σU	30,000	5,755	OK	5,823	OK	5,804	OK
			OK		OK		OK

The conditions of stability analysis are as below:

Load Condition

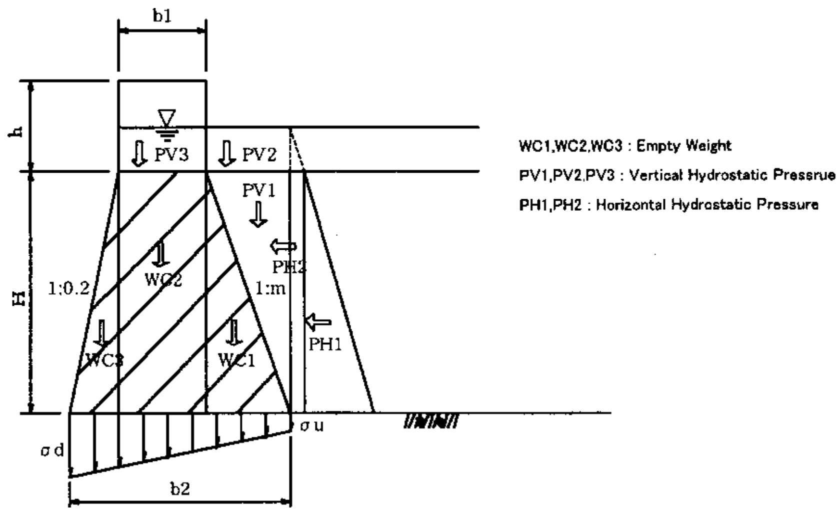
List of Design Loads

	Ordinary Times	Debris Flow	Flood
Dam Height is less than 15m		Hydrostatic Pressure, Pressure of Sedimentation Pressure of Debris flow	Hydrostatic Pressure

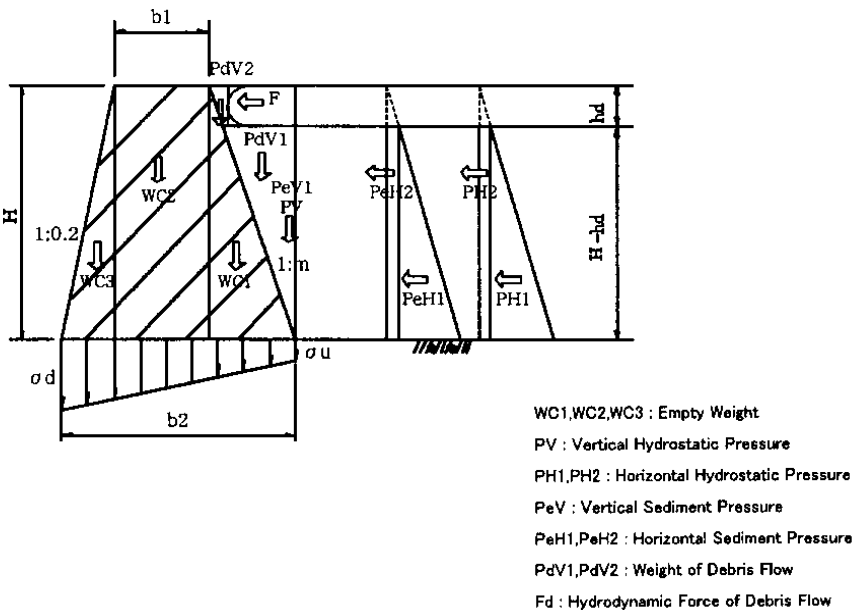
Stability Condition

1. The acting line regarding resultant force of empty weight and external force is to be within the one-third area of the center of the dam bottom so that the tensile stress at the upstream end of the dam may not occur.
2. No sliding between the dam bed and the foundation bed.
3. The maximum stress in the dam structure must not exceed the allowable stress of the materials of the dam. The maximum pressure against the dam foundation must be within the bearing capacity of the foundation.

In Case of Flood



In Case of Debris Flow



Sketch of Design Load

2) Cutoff

Cutoff is set in order for the apron to be horizontal and for vertical walls to attach to the riverbed.

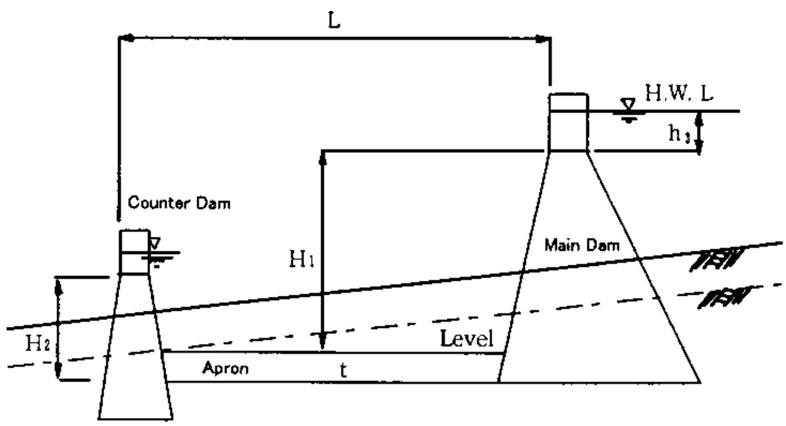
Judging from each riverbed slope, the length of the cutoff in the Pawa River is 0.5m, and 1.0m in the Anoling River.

3) Protection Works of Front Yard

The length of the protective works in the front yard was discussed and examined with empirical formula and Bligh's Formula. Thus the safety side values have been adopted.

Dimensions of Protection Works of Front Yards

	Bligh formula				Empirical Formula					Length of front apron
	q $m^3/s/m$	D (m)	W (m)	L (m)	H (m)	h_3 (m)	h (m)	t (m)	l (m)	
Pawa-burabod	5.84	5.0	8.0	**21.7**	6.5	2.20	5.0	1.5	21.60	22.0
Anoling L	5.68	5.5	8.4	**22.5**	7.0	2.20	5.5	1.5	23.10	23.5
Anoling R	5.51	5.5	8.4	**22.1**	7.0	2.10	5.5	1.5	22.80	23.5



Form of Protection Works of Front Yards

<u>Bligh's Formula</u>

$L = 0.67\ C_o \sqrt{Hb \cdot q}$

Coefficients of Infiltration (C_0)

Classification	C_0
Fine Sand or Silt	18
Fine Sand	15
Coarse Sand	12
Mixing of Sand and Gravel	9
Coarse Sand with Cobble	4~6

L : Length of Apron + length of protection works for riverbed in Downstream (m)

C_0 : Coefficient of Seepage Line (From among the level-4 to 6 coarse sand with cobble in the chart above, the maximum value 6 is adopted.)

D : The height between the height of crown of apron and the top of the main.

H_b : Generally, by measuring the height between the apron crown and the top of the main body,
H_b=D

q : Discharge in Unit Width (m^3/s)

Empirical Formula

L = $(1.5 \sim 2.0)\ (H_1 + h_3)$

L : Dimension between Main Dam and Counter Dam

H_1 : Height of Main Dam measured from Apron Crown (m)

h_3 : Overflow Depth of Main Dam (m)

2.3 Training Dike

(1) Type of Training Dikes

We propose the three types, A, B, and C for the types of Training dike. These types are adopted respectively according to the flowing form of gradient and soil or the variation of the riverbed with the impact pressure and erosion. The characteristics of the three types are as follows :

- CSG type is basically adopted in the section where gradient of the mountain stream is steeper than 1/30 and thereby debris flow is expected. This CSG type is divided into the two types below.
- We recommend the type A, which use CSG entirely, in the sections of upstream sand pocketing and along the trench which have the possibility of overflowing the crown.
- We recommend the type B, which use CSG only for the riverside, in the sections which have little possibility of overflowing the crown.

- We recommend the type C, which protects the riverside of embankment with the riprap, in the sections for bed-load transport or traction, whose bed slope of the riverbed is gentle (less than 1/30).

Reference Book: *Debris Flow Survey Points in Hazardous Mountain Streams and Hazard Area* (Draft), December, 1998 (Japanese Edition): Japanese Original Title/*DosekI-Ryu ni Kansuru Kiken Keiryu oyobi Kiken Kuiki no Chosa Yoryo (An)*

In volcanic mountainous slope area which can be considered as a hazard area of debris flow, if the area has experienced debris flow, the actual steepness of the slope is referred to, otherwise the bed slope is to be set up to 2° （around 1/30）.

Past inundation experiences indicate that debris flows came to stop at the point of around 2° bed slope.

(2) Structural Details

The crown width should be 4.0m or above taking into consideration the constructional feature of the roll and the fact that the crown is used as a road. Especially, the embankment must be 6.0m with 1.0m allowable width on each edge.

The basic effective height of dike is to be 5.0m, according to the fact that previous fluctuations of the riverbed were from 1.0m to 2.0m, and to the calculation based on the formula: deposit depth 2.0m + water depth 2.2m+allowable height 0.8m.

- Embedment Depth
  Due to the 1.0-2.0m riverbed fluctuation, the depth of embedment of the existing installations are short of 1.0m, thus the depth of embedment of this plan is to be 2.0m.
- Slope Gradient
  CSG is adopted to the case in which the slope gradient is 1:1.2 and the construction with non-framework is possible. The maximum standard slope gradient value 1:2.0 is adopted for embankment.
- Slope Protection against Erosion
  At the riverside, riprap is done with Boulder Facing, and at inland vegetation the mat is built as embankment in order to prevent erosion.

(3) Foot Protection against Erosion

Gabbion is set up in order to prevent the foot part of the structures from erosion. In the upstream area where debris flow would collide, it is necessary to set up boulders all over the training dike at the time of channel grading.

References

The width of Gabbion must be at least 3.0m, judging from the formuli below.

$$B = Zs / \sin\theta = 0.8 * 2.2 / \sin 35^\circ \fallingdotseq 3.0$$

Zs : Maximum Scouring Depth = 0.8 × Design Flood Depth

θ : Angle of Repose θ = 35°

2.4 Volume of Construction Works

Volume of Installations

	Concrete					Boulder facing	CSG	Excava-tion	Enbank-ment	Gabbion	Coco fiber erosion control net with seed	Cost
	Dam Body	Concrete facing	Apron	Vertical wall	Total							
	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^2)	(peso/m)
					2,500	2,000	400	120	200	1,500	40	
Sabo dam Overflow portion												
Pawa-Burabod Rv Sabo dam		26.72	13.50	5.40	45.6		64.4	87.3				150,200
Anoling Sabo dam		27.84	14.25	5.40	47.5		66.8	90.6				156,300
Sabo dam Non-overflow portion												
Pawa-Burabod Rv Sabo dam		24.92			24.9		117.3	57.1				116,000
Anoling Sabo dam		24.92			24.9		117.3	71.0				117,700
Training Dike Type A		6.59			6.6	5.5	65.0	34.3		3.0		62,100
Training Dike Type B		1.26			1.3	5.1	35.3	22.7	40.0	3.0	15.3	43,400
Training dike Type C						6.5		7.8	67.8	3.0	18.3	32,700

3. CHANNELING WORKS

3.1 Training Dikes

(1) Type of Training Dikes

Different types of training dikes are adopted according to the soil flowing form and the topography of the construction site.

- CSG type area is found where riverbed slope is more than 1/30, trench is not formed, and inundation is expected due to the accumulation of soil.

CSG type area :

- Bank protection type area is found where riverbed slope is less than 1/30, bed-load transport or traction occurs, and trench is likely to be formed.

Bank protection type area: the downstream area from the crossing point of right and left sides of the Pawa-burabod River and the Anolimg River.

(2) Detailed Structures

CSG Type

- Crown Width
  Since the design discharge is less than 500m^3/s, the crown width in this plan is to be 3.0m, in relation to the crown width of embankment.
- Dike Height
  The effective height is set by the formula (water depth＋allowable height), to which the 2.0m depth of embedment is added to set the dike height.
- Slope Gradient
  The slope gradient is to be 1:1.2 so that non-framework construction may be possible.

Itemized Statement of Calculated Bank Protection Height

River Name	Year	Discharge (m^3/s)		River Width	Bed Slope	Sidewall Slope	Rough-ness	Water Depth	Sectional Area	Wetted Perimeter	Hydraulic Radius	Velocity
		Pure Water	Debris Water	(m)	1/n	1:m	*n*	h_1(m)	A(m^2)	P(m)	R(m)	V_1(m/s)
Pawa-Burabod	20	216.0	240	30.0	1/40.0	1:0.5	0.040	1.555	47.849	33.476	1.429	5.016
Anoling L	20	209.0	230	30.0	1/30.0	1:1.2	0.040	1.365	43.186	34.264	1.260	5.326
Anoling R	20	240.0	260	30.0	1/30.0	1:1.2	0.040	1.469	46.659	34.589	1.349	5.572
Anoling D	20	427.0	470	40.0	1/40.0	1:0.5	0.040	1.956	80.161	44.374	1.806	5.863

Sediment Concentration 0.1

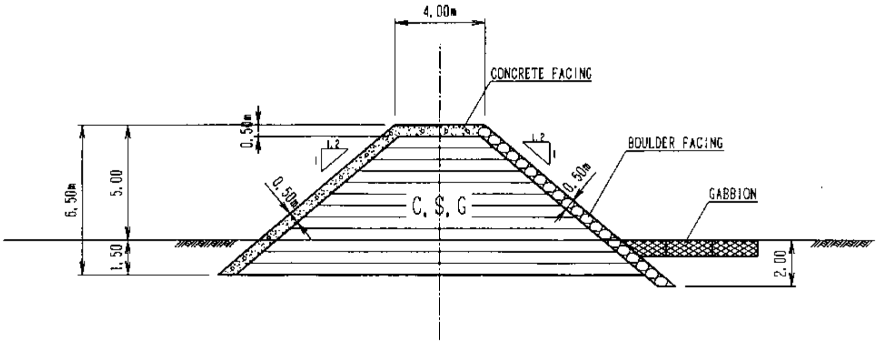
River Name	Year	Discharge (m^3/s)		River Width	Bed Slope	Sidewall Slope	Water Depth h^2(m)		Allowable Height	Effective Height	Height
		Pure Water	Debris Water	(m)	1/n	1:m	Calculated	Accepted	(m)	(m)	(m)
Pawa-Burabod	20	216.0	240	30.0	1/40.0	1:0.5	1.555	1.6	0.8	2.4	4.4
Anoling L	20	209.0	230	30.0	1/30.0	1:1.2	1.365	1.4	0.8	2.2	4.2
Anoling R	20	240.0	260	30.0	1/30.0	1:1.2	1.469	1.5	0.8	2.3	4.3
Anoling D	20	427.0	470	40.0	1/40.0	1:0.5	1.956	2.0	0.8	2.8	4.8

(3) Volumes of Construction Works

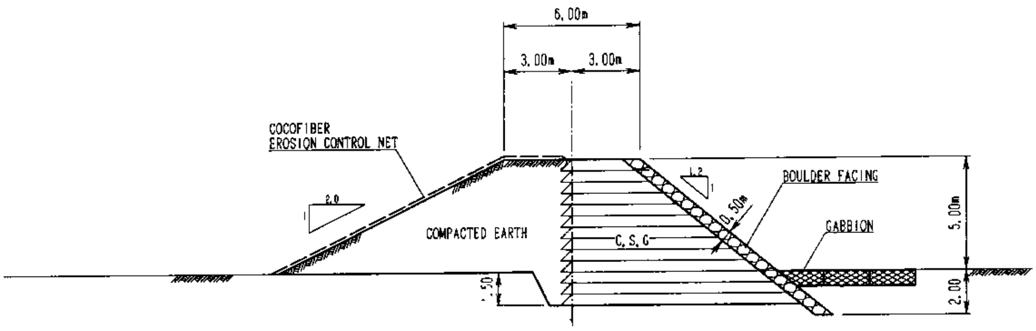
Itemized Statement of Calculated Volumes

	Concrete				Boulder facing	CSG	Riprup Rock	Excava-tion	Gabbion	Cost one side	Cost
	Concrete facing (m3)	Base (m3)	(m3)	Total (m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(peso/m)	(peso/m)
				2,500	2,000	400	400	200	1,500		
Training Dike CSG type											
Anoling L river	1.00			1.0	6.6	26.2		33.2	0.0	32,800	65,600
Anoling R river	1.00			1.0	6.8	27.4		33.6	0.0	33,800	67,600
Training Dike general type											
Pawa-Burabod River		0.9		0.9	2.5		1.9	53.0	3.0	23,100	46,200
Anoling Down river		0.9		0.9	2.9		2.1	9.0	3.0	15,200	30,400

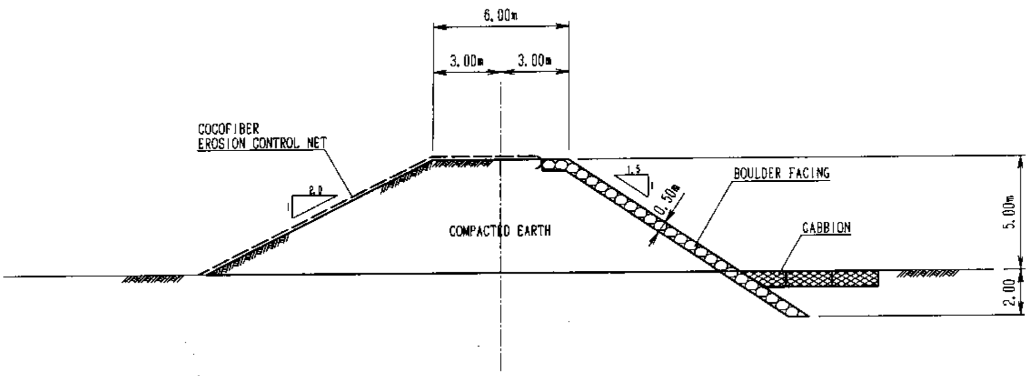
SPUR DIKE(A)



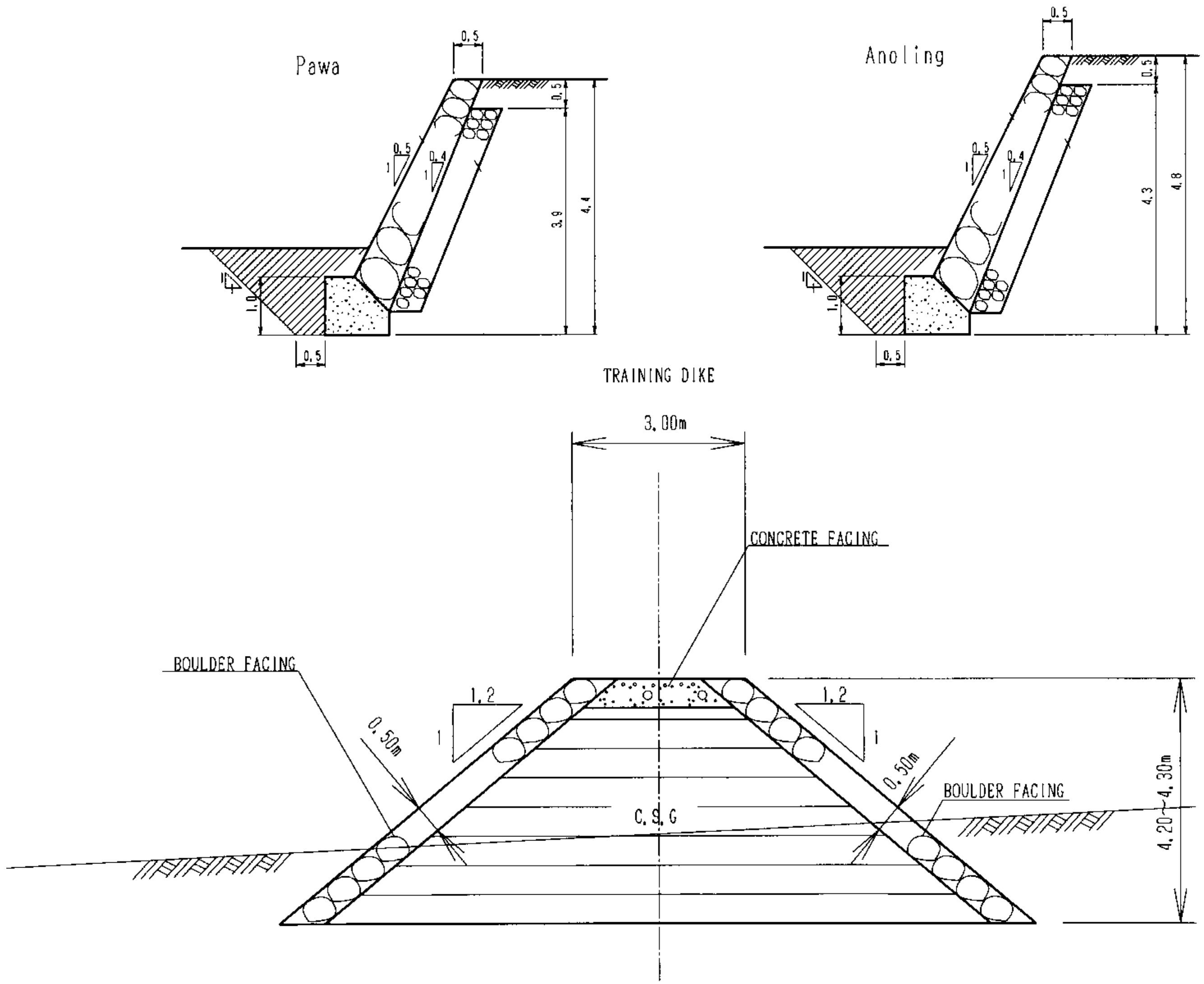
SPUR DIKE(B)



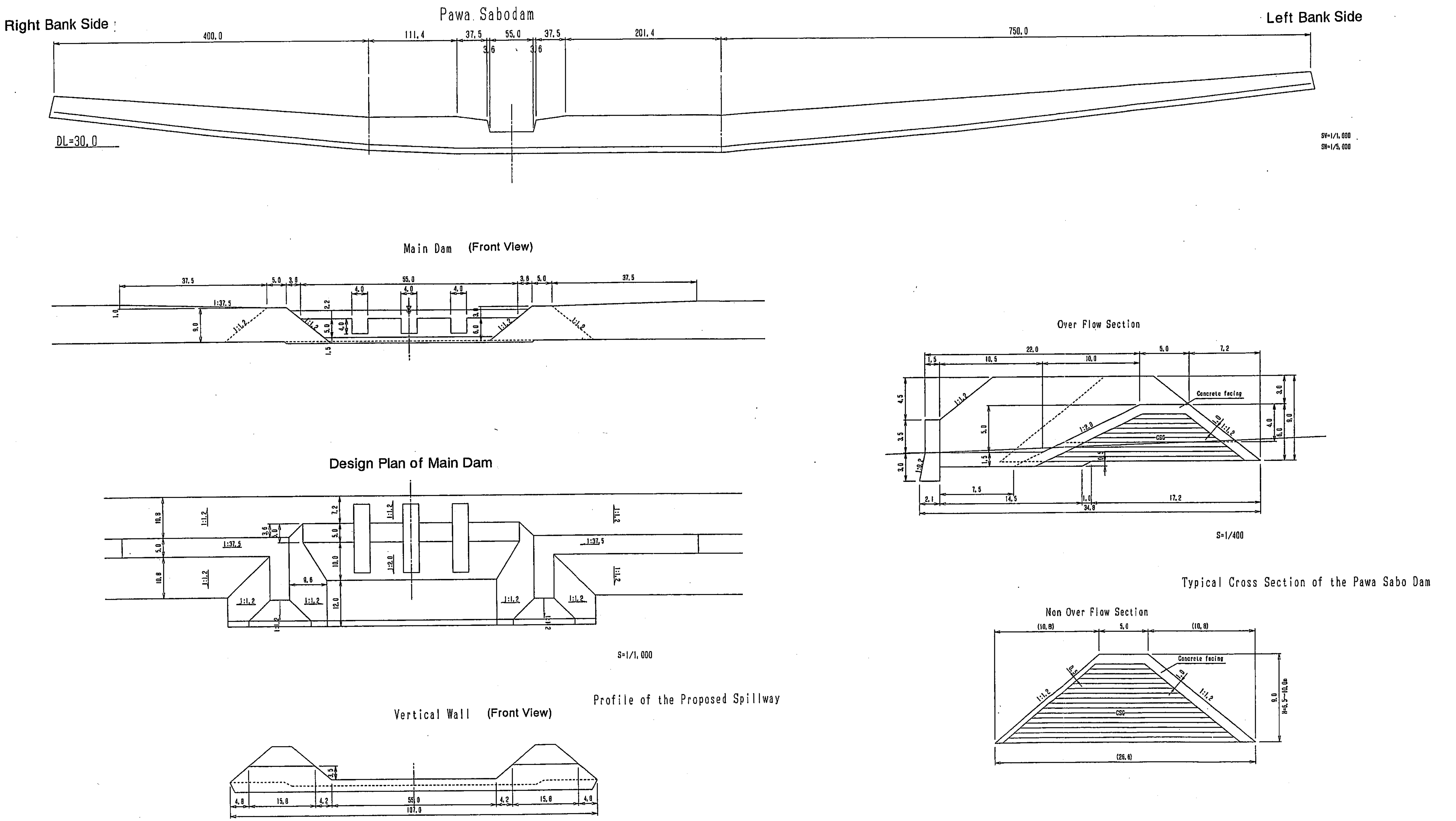
SPUR DIKE(C)



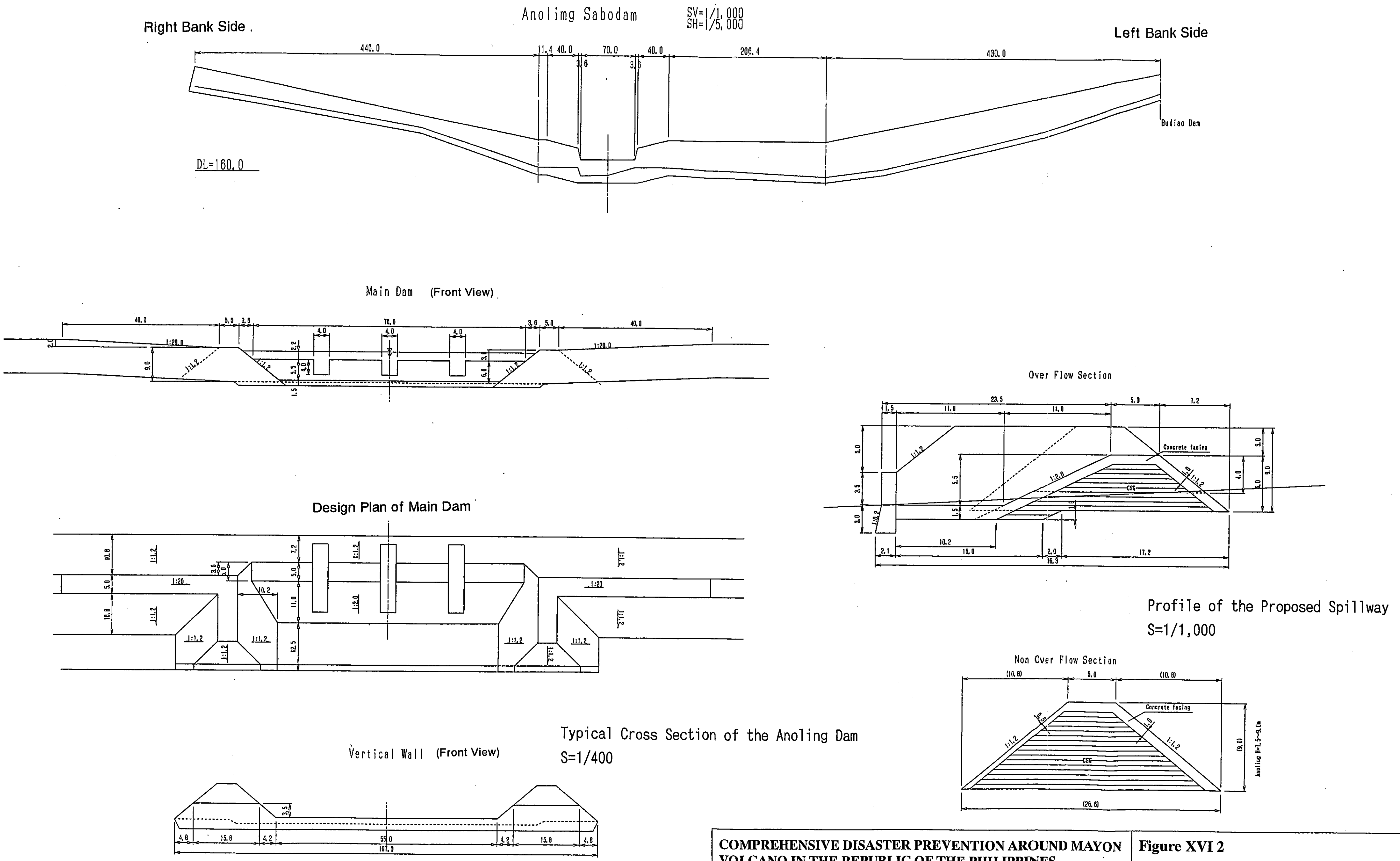
Typical Cross Section of Spur Dike



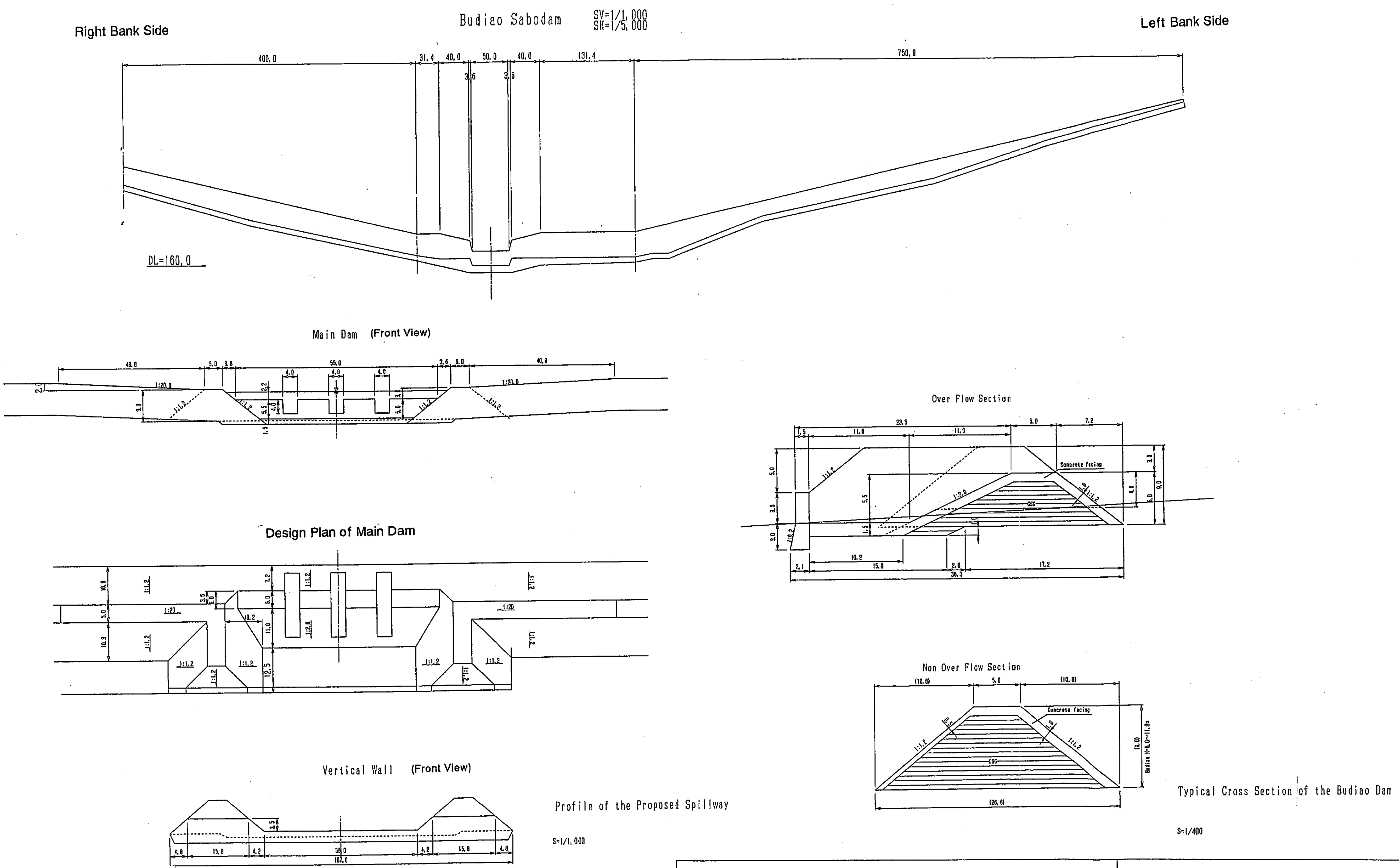
Typical Cross Section of Training Dike



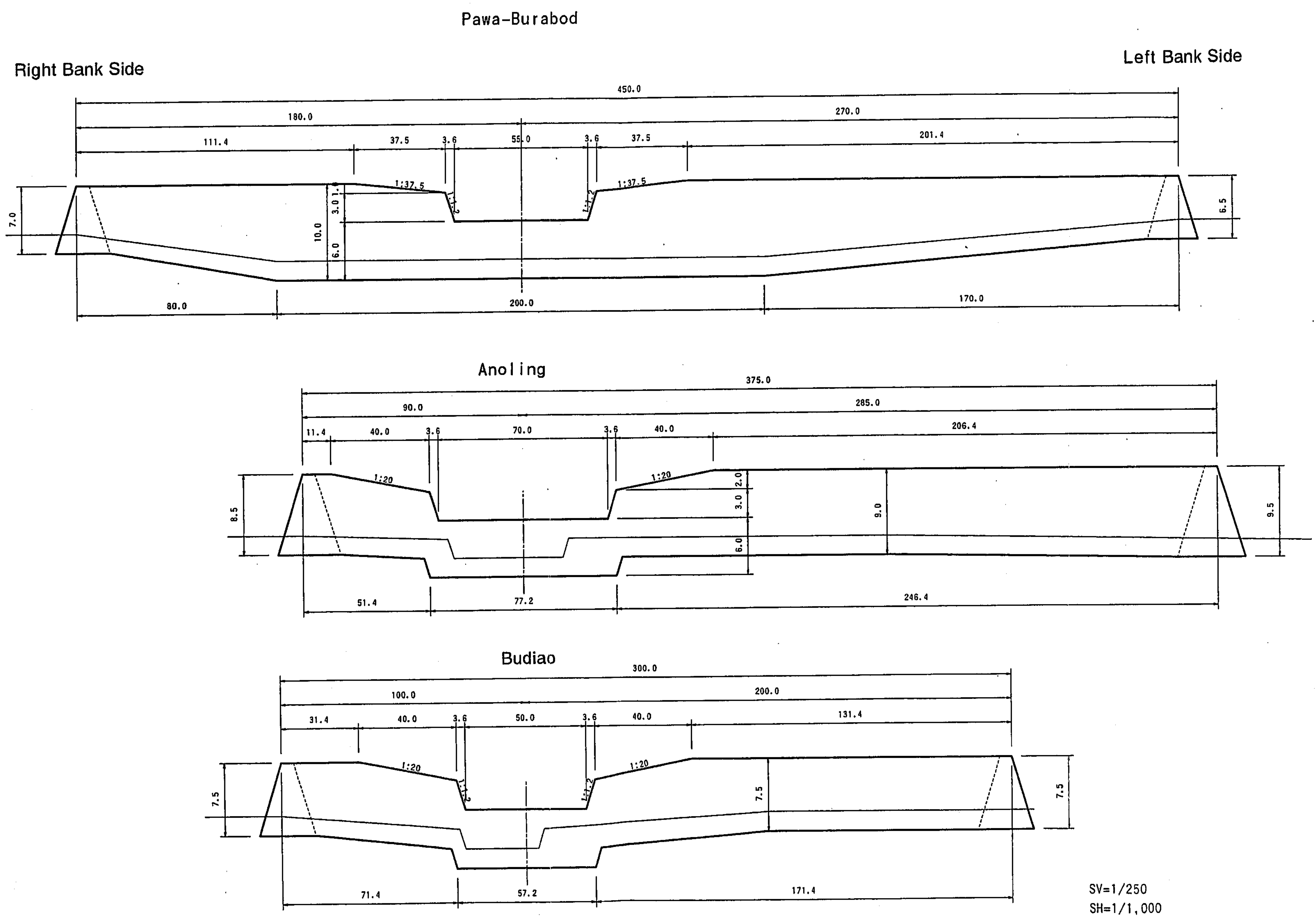
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	Figure XVI 1 Facility Design of Pawa-Burabod River
JAPAN INTERNATIONAL COOPERATION AGENCY	



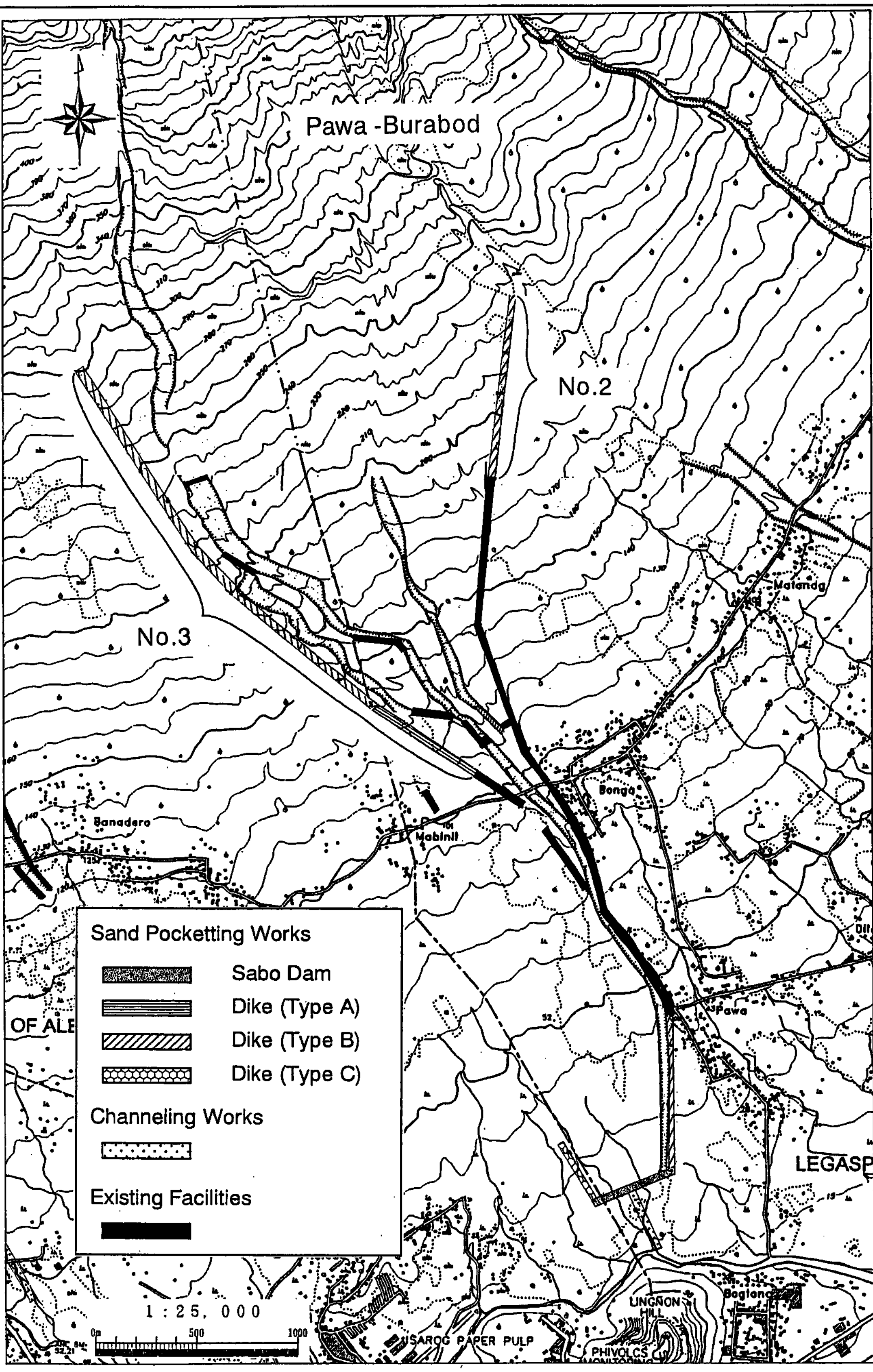
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	Figure XVI 2 Facility Design of Anoling River
JAPAN INTERNATIONAL COOPERATION AGENCY	



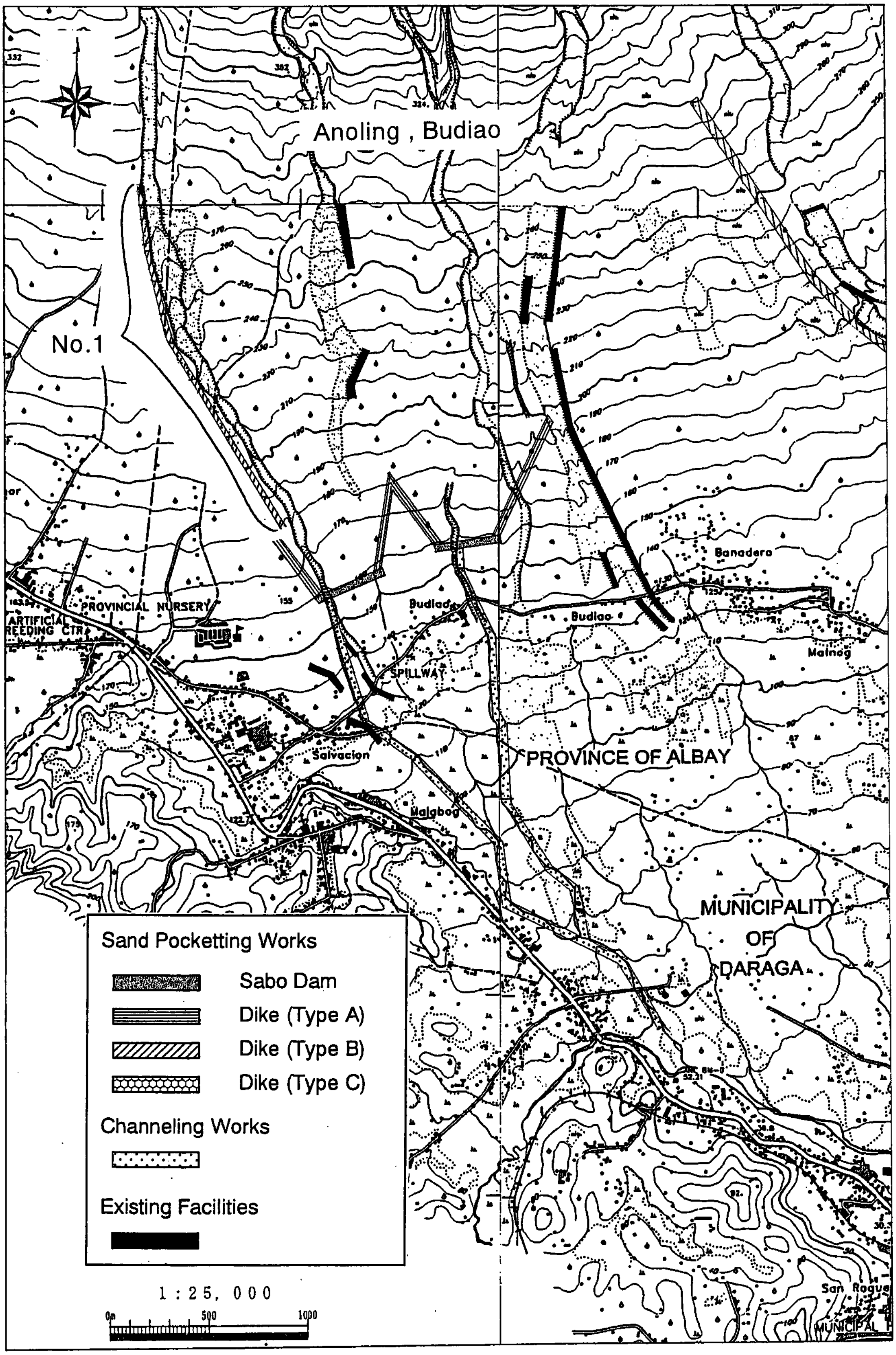
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure XVI 3** **Facility Design of Budiao River**
JAPAN INTERNATIONAL COOPERATION AGENCY	



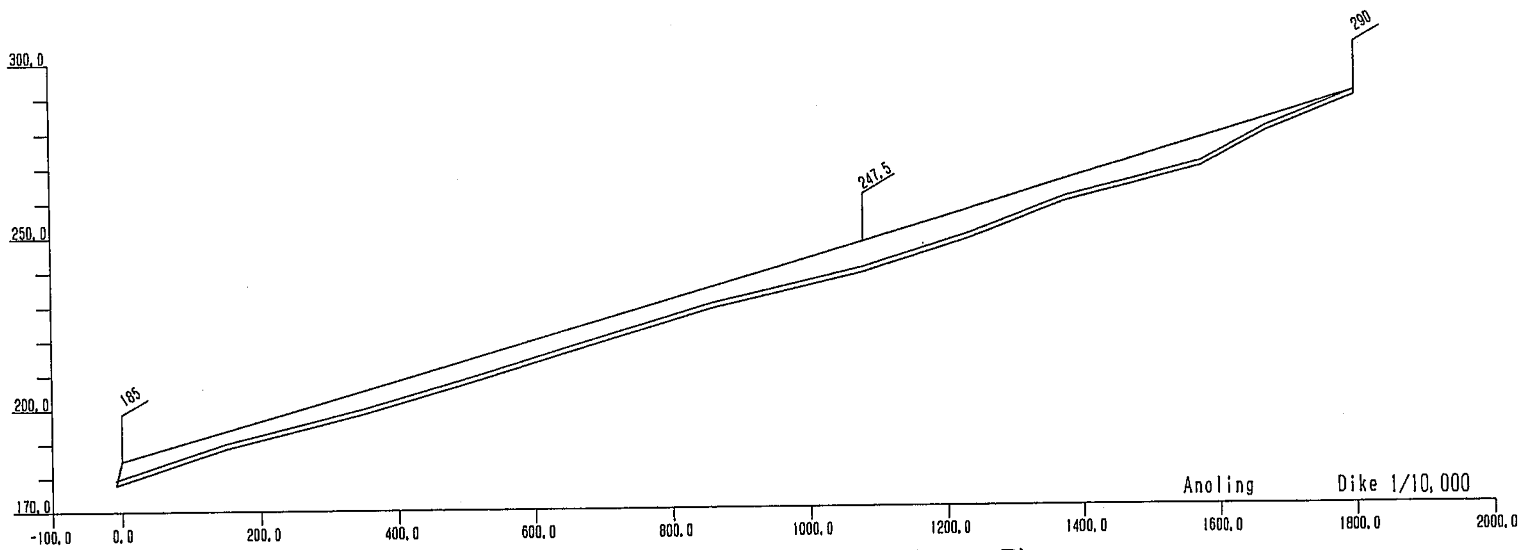
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure XVI 4** **Enlarged Front View of Sabo Dam**
JAPAN INTERNATIONAL COOPERATION AGENCY	



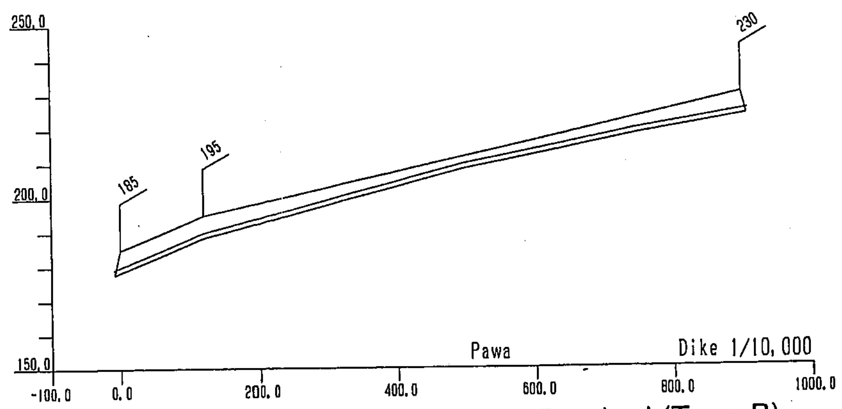
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure XVI 5** **Location Map of Dike Profile No.1 and No.2 in Figure XVI 7**
JAPAN INTERNATIONAL COOPERATION AGENCY	



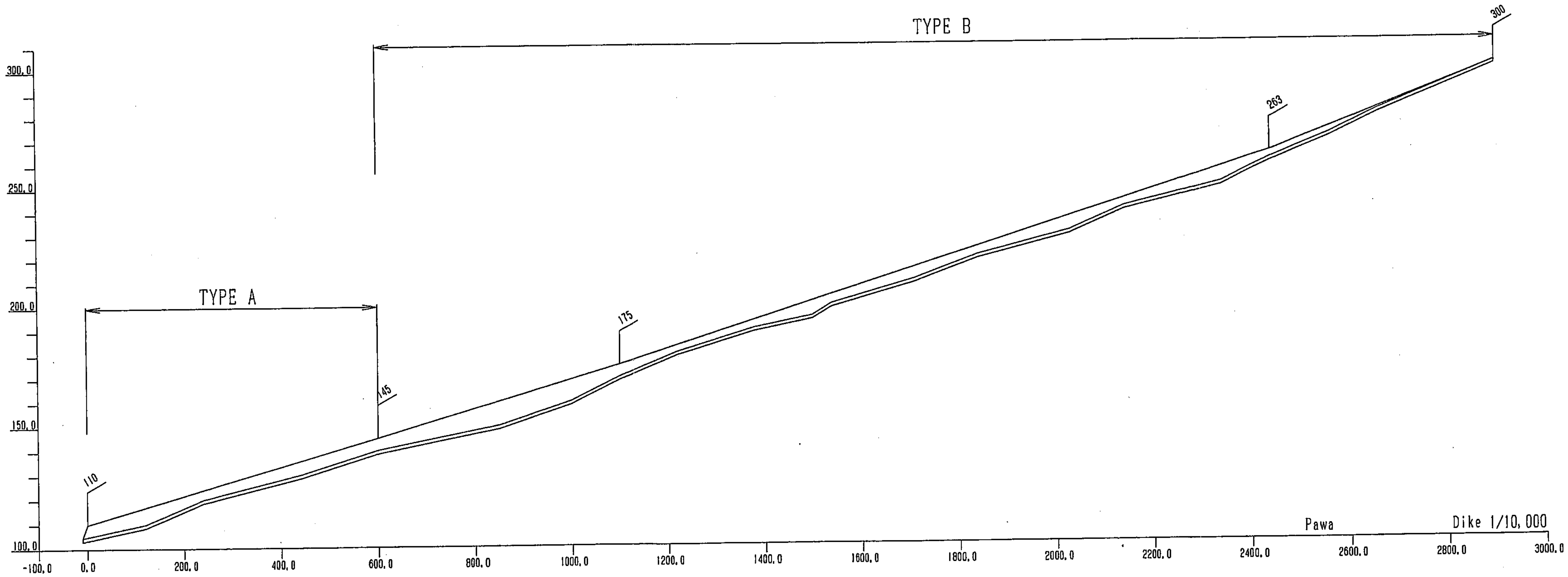
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure XVI 6**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Location Map of Dike Profile No.3 and No.4 in Figure XVI 7**



No.1 Profile of Dike , Anoling (Type B)



No.2 Profile of Dike , Pawa-Burabod (Type B)



No.3 Profile of Dike ; Pawa-Burabod (Type A , B)

COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	Figure XVI 7 Profiles of Dike
JAPAN INTERNATIONAL COOPERATION AGENCY	