No.

The Department of Water Induced Disaster Prevention, Ministry of Water Resources
The Department of Roads, Ministry of Physical Planning and Works
The Republic of Nepal

THE STUDY ON DISASTER RISK MANAGEMENT FOR NARAYANGHARH – MUGLING HIGHWAY

FINAL REPORT

Volume IV
Technical Guide

February 2009

JAPAN INTERNATIONAL COOPERATION AGENCY

NIPPON KOEI CO., LTD.

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COMPOSITION OF REPORTS

Volume	Report Name	Language
Volume I	Summary	English
Volume II	Main Report	English
Volume III	Data and Drawing	English
Volume IV	Technical Guide	English

TECHNICAL GUIDE

ON

SABO AND ROAD SLOPE PROTECTION WORKS

FEBRUARY 2009

PREFACE

The technical guide is prepared as a technical reference for DWIDP and DOR. Its main objective is to assist DWIDP and DOR Engineers or also other technical staff concerning the planning, design, construction and supervision of road slope disaster mitigation measures. The policies for preparing the technical guide are as follows:

a) To arrange basic planning and designing method on countermeasures for sediment related disasters which is applied in Nepal,

b) To suggest the improvement methods and design procedures in response to the recorded problems,

c) To introduce new and practical slope protection and prevention methods which can be applied for roads and slopes of Nepal in the near future,

d) To suggest regular maintenance works to keep the slope and other road structures in effective condition.

Chapter 1 contains Sabo Work, which includes basic design procedure of gabion and concrete sabo dam and box culvert and design method of sabo dam which is constructed by soil cement is introduced in Chapter 2.

Designing slope protection methods for road slope are described in Chapter 3 to Chapter 7 in which include design of basic slope protection methods such as cut work (chapter 3), slope drainage (chapter 4), slope protection works (Chapter 5), retaining walls (Chapter 6), rock fall prevention works (Chapter 7).

Importance of maintenance work of countermeasures for sediment related disasters is briefly describes in Chapter 9.

Guide, which was prepared in a short period of time, is a very preliminary technical material, but hopefully can be utilize by DWIDP and DOR technical staff with future engineering practice in sabo and road slope disasters mitigation.

TECHNICAL GUIDE

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The figures and the tables in the report which their references are not described were prepared by the JICA Study Team.

CHAPTER 1

SABO WORKS

1.1 General

Debris flow is the fast movement of rock fragments, earth and mud mixed with water, along a valley or a mountainous stream. Because of its high speed, debris flow is most dangerous to life and property because it destroy objects in its path.

Along the N-M highway, debris flows is one of the most dangerous and severe road disasters. As a structural measure, sabo dam including gabion and concrete has been widely constructed on the mountainous streams which cross the highway.

Most of the constructed sabo dams, especially gabion sabo dams, have some structural defects, as observable along the highway. The main problems regarding to these sabo dams are summarized as follows:

a) Sabo dams were mostly constructed with foundation works or embedded on the bedrocks. This is also the main causes of deformation of sabo dams. In designing and constructing a sabo dam, the bearing ground should be excavated to a depth required for placing a footing if it is bedrock. In the case of earth or gravel ground, foundation treatment, for example, leveling concrete is always required.

b) The crest part of gabion sabo dams were severely damaged due to erosion by debris flow. Because of frequent occurrence of debris flow, protection on the crest part of a gabion sabo dam should be carefully examined. As an idea, plain concrete, for example, 10 to 30 cm thick is designed to cover the crest part of a gabion sabo dam so as to prevent damage of wire mesh box from massive debris flow sediments.

c) Axial of sabo dam was not designed perpendicular to the direction of river flow. This may guides river water and debris flow to run toward valley banks, largely eroding the stream banks and leading to bank collapse. Such sabo dam, because it may block debris flow deposits to smoothly flow downstream, in the worst spreads out laterally sediments around the bank, causing an unexpected damage.

d) In some cases, overflow section is too small for discharge flood peak. In general, because sabo dam is constructed on the river or mountainous stream, the design flood peak discharge should be calculated and thereby overflow section is determined.

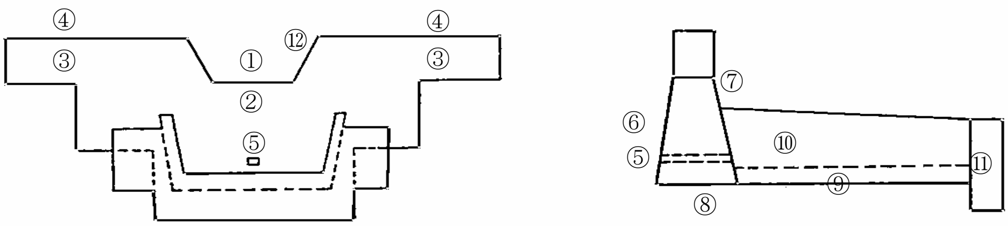
This chapter, therefore, taking account of the above-mentioned problems, describes in detail design procedures of various parts of a concrete sabo dam and some notices in construction.

In addition, prior to design of sabo dam, a master plan should be generally formulated to determine the arrangement of all sabo facilities. The formulation of a master plan shall refer to “Technical Guidelines for Debris Flow Measures”, *Sediment Control Depart, River Bureau, Ministry of Construction, Japan*, July, 2000.

1.2 General Considerations

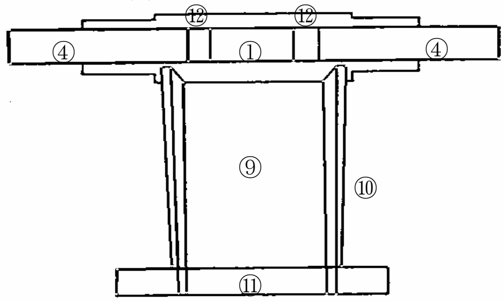
1.2.1 Purpose and Functions of Sabo Dam for Debris Flow

Sabo dams are the most common countermeasure against debris flow. They are generally constructed from masonry, concrete, reinforced concrete, steel cribs, etc. Figure 1.2.1 diagrammatically illustrates the dam section and nomenclature.



(a) Front view

(b) Side view



(c) Plan view

①	Spillway	⑦	Downstream slope
②	Spillway crown	⑧	Base of dam
③	Wing	⑨	Front apron
④	Wing crown	⑩	Side wall
⑤	Drain hole	⑪	Vertical wall
⑥	Upstream slope	⑫	Side of spillway

Figure 1.2.1 Diagrammatical Dam Section and Nomenclature

Sabo dams have following four functions.

a) Spur consolidation

b) Riverbed erosion control

c) Riverbed sediment runoff control

d) Debris flow control

(1) Spur Consolidation

A function for spur consolidation prevents hillside failure and further collapse of an adjacent area by raising the riverbed at a spur (hillside foot) through the accumulation and consolidation of sediment (Figure 1.2.2). It is constructed immediately below the hillside to be protected from erosion. The height of the dam should be adequate to contain the projected sediment volume.

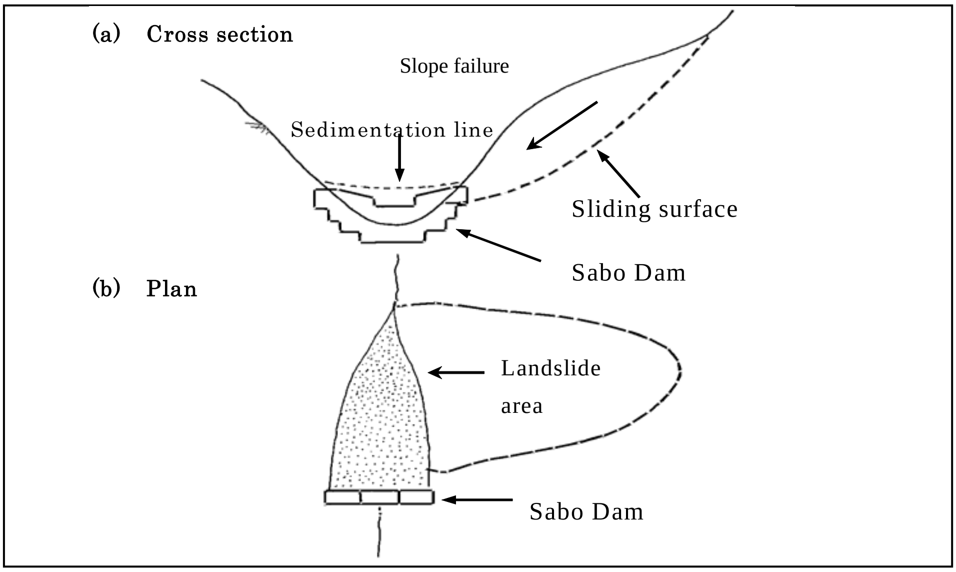


Figure 1.2.2 Typical Example of Landslide Stabilized by a Sabo Dam

(2) Riverbed Erosion Control

A function for riverbed erosion control prevents riverbed erosion and sediment production (Figure 1.2.3). It is constructed immediately downstream of a riverbed erosion area. Its height should be adequate to contain the riverbed erosion and sediment accumulation areas.

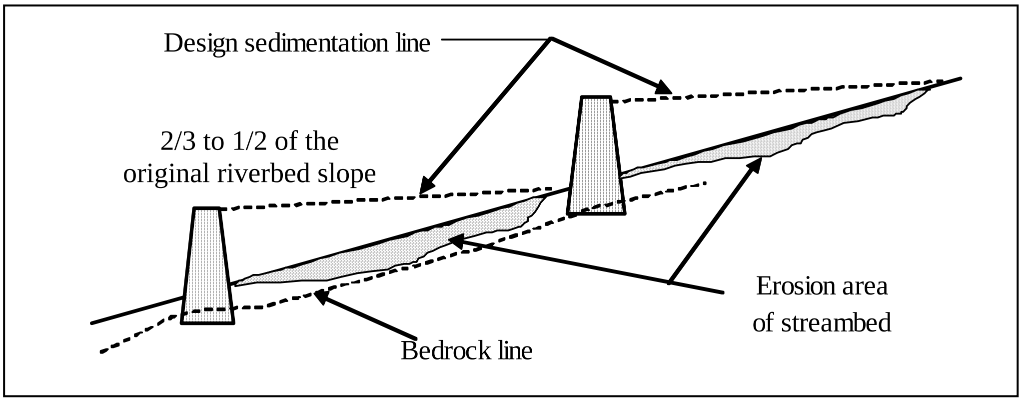


Figure 1.2.3 Stepped Dams for Riverbed Erosion Control

(3) Riverbed Sediment Control

A function for riverbed sediment control prevents further transport of unstable sediments that have accumulated on the riverbed. It is constructed immediately downstream of the accumulated riverbed sediments. The height of the dam should be adequate to contain the riverbed sediments within the accumulation area.

(4) Debris Flow Control

A function for debris flow control prevents or controls debris flow sediments. Its location and height is determined according to its purpose, such as prevention and elimination of debris flow.

In planning a sabo dam for the prevention of debris flow, its accumulating capacity is determined provisionally to be more than 10% of the design excess sediment that causes debris flow.

For eliminating debris flow, the location, height, shape and number of dams should be able to change debris flow area into a bed-load area.

1.2.2 Location and Height of Sabo Dam

In designing a sabo dam, the location and scale (height and section) of the dam is determined according to its purposes. The height of dam is sometimes restricted by the geological and topographical conditions of the dam site, and therefore these should be given due consideration. In principle, the dam is located on stable ground beyond the unstable area because sabo dams are easily destroyed by slope failure when constructed in an unstable area. Locating the dam in a narrow section with a wider section upstream is desirable for improving cost-effectiveness. Also, the sabo dam should be located close to the related road.

In determining the location of a sabo dam, the following points should generally be examined in order to serves its purposes:

a) Firm bedrock is preferable to have a stable foundation for concrete sabo dam. Where the gravel ground is encountered, the height of sabo dam should be less than 8 m considering strength of gravel foundation.

b) Downstream just after the place where sediments are deposited.

c) Upstream just before the width of torrent becomes wider

d) A curbed portion of torrent is not preferable

e) Stepped arrangement

In case the torrent or stream is long or the volume of sediments is estimated to be large, a series of sabo dams may be arranged in a step-like manner as shown in Figure 1.2.3 above.

1.3 Design Considerations

1.3.1 Design Procedure of Sabo Dam

Sabo structures are designed according to the intended functions/purposes and should be stable enough to withstand all the expected design forces. Figure 1.3.1 gives the general design procedure for a concrete sabo dam for debris flow.

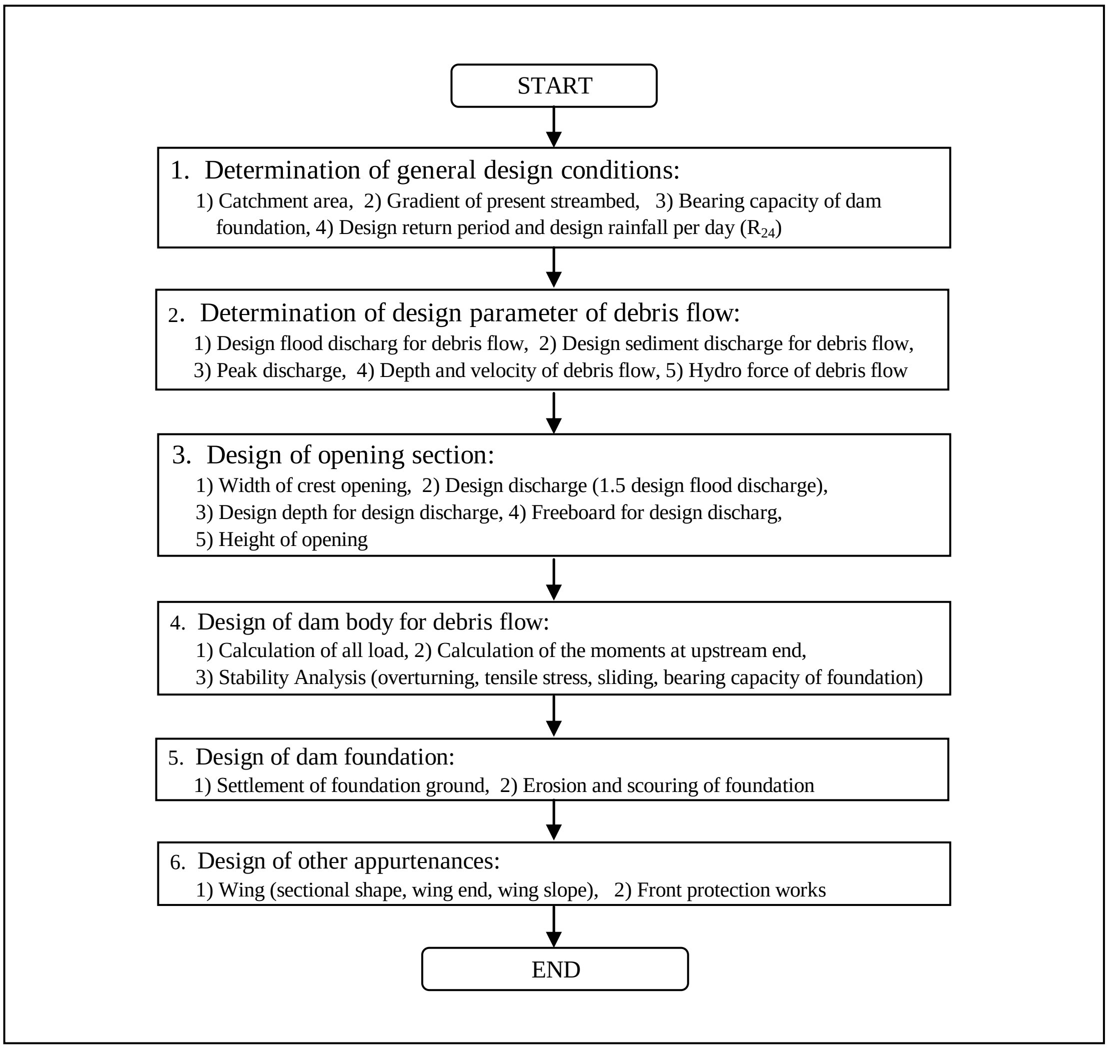


Figure 1.3.1 Design of Concrete Sabo Dam for Debris Flow

In this section, mainly item α s of discharge and design of open section are described. So other design procedure shall refer to “Technical Guidelines for Debris Flow Measures”, *Sediment Control Depart, River Bureau, Ministry of Construction, Japan*, July, 2000.

1.3.2 Design of Open Section

In designing the opening section for debris flow, the width of the crest opening, generally over 3 m, should be determined on the basis of the width of the existing streambed. The height of the opening is determined considering the design depth, freeboard and the maximum diameter of the boulders expected to be contained in the debris flow.

(1) Width of Crest Opening

The width of crest opening shall be over 3m. The width shall be decided considering the width of existing streambed.

(2) Design Discharge

The design discharge of Sabo dam is the necessary discharge for the design of Sabo dam and is different from the channel works.

Design discharge (Q) should be determined from the equation below (1.1). And the ratio of sediment concentration shall be added to the design flood discharge (Q'), as follow (1.2):

$$Q = (1+\alpha) \times Q' \qquad (1.1)$$

$$Q' = 1/3.6ciA \qquad (1.2)$$

Where:

Q = Design flood discharge including sediment (m^3/s)

Q'= Peak flood discharge calculated by Rational formula (m^3/s)

α = The ratio of sediment concentration (See 1.3.1)

c = Runoff coefficient

i = Mean rainfall intensity during the flood concentration (mm/h)

A = Drainage area (km^2)

Design discharge should be determined from the rainfall depth (i) of 100years return period or the maximum rainfall depth in past records, whichever is larger. Along the Narayangharh - Mugling Highway, the maximum rainfall depth in past records is 446.2mm/day, so 450mm/day can be applied which is maximum rainfall depth recorded in 2003 disaster.

The design discharge of Sabo dam shall be decided by considering the ratio of sediment concentration (α). α is usually 0.1～0.3, but if there is collapse upstream of sabo dam site, proposed value of α should be 0.5.

Table 1.3.1 Proposed ratio of sediment concentration (α)

Applicable condition	*α*
Normal	0.1～0.3 (ordinarily used is 0.1)
Relatively small river with collapse upstream of the dam site	0.5

(Proposed value referred to Japanese standard considering condition of study area)

Table 1.3.2 Runoff Coefficients (c)

Condition of the Area	*Values of Coefficient (c)*
Steep mountain	0.75-0.9
Mountain of tertiary area	0.7-0.8
Undulating land	0.5-0.75
Rivers in mountain	0.75-0.85
Small rivers	0.45-0.75
Major stream on plain area	0.5-0.75

Source: Hydrology by Monobe

(3) Design Depth for Design Discharge

The height of crest is calculated by the following formula.

$H_3 = h_3 + h_3'$

Where:

H_3 = Height of crest opening (m)

h_3 = Depth of design flood discharge (m)

h_3' = Freeboard (m)

The depth of flood discharge is calculated by the following Trapezoidal Weir Formula.

$$Q = 2/15 \times C \times \sqrt{2g} \times (3B_2+2B_1) \times h_1^{3/2} \qquad (1.3)$$

Where:

Q = Design flood discharge (m_3/s)

C = Coefficient of opening discharge (0.6-0.66)

G = Acceleration of gravity (9.8m/s^2)

B_2= Base width of opening (m) at least 3m

B_1= Flow width of water surface (m)

m_2= Side slope of opening

Adapting m_2=0.5 and C=0.6, substituting to the above formula, resulting formula will be;

$$Q = (0.71h_3 + 1.77B_1) \times h_3^{3/2} \quad (1.4)$$

In addition, the freeboard depends on the design flood discharge and Table 1.3.3 gives the proposed freeboard, h'_3. When the value of freeboard should be determined, priority of roads should be considered. If not so high priority, 0.6m should be chosen.

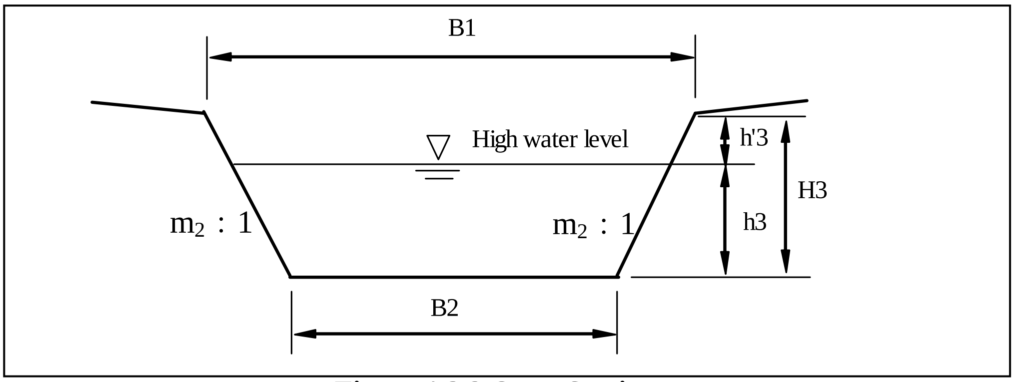


Figure 1.3.2 Open Section

Table 1.3.3 Proposed Freeboard

Proposed Discharge	Freeboard (m)
Below 200 m3/sec	0.6
200 – 500 m3/sec	0.8
500 m3/sec or above	1.0

1.3.3 Design of Dam Body

The design of a dam body is based mainly on the stability analyses of the dam body in terms of overturning, sliding and foundation bearing resistance. The general criteria for stability analysis for sabo dams are summarized in Table 1.3.4. Stability against the settlement of the foundation ground as well as the potential for the dam base to slide across the foundation ground should be considered.

Table 1.3.4 Criteria for Stability Analysis of a Dam Body

Item	Value	
1) Overturning	e ≦ B/6	
2) Sliding	H≧15m Rock Base: Fs≧4.0 Gravel and Sand Base: Fs≧1.5	H<15m Gravel and Sand Base: Fs ≧ 1.2
3) Bearing capacity	$q \leqq q_a$	

Note: e = Acting range of resultant, Fs = Factor of safety, B = Base width of dam body.

The combination of loads to be used for the stability calculations of the dam section for sabo dams considering the debris-flow hydro force are summarized in Table 1.3.5. The unit weight of water in the calculation of the hydrostatic pressure in a debris flow should be 11.8 kN/m^3 because the earth and uplift pressures are not considered.

Table 1.3.5 Combination of Loads for Stability Calculations of a Dam Body

Dam height	During ordinary time	During debris flow	During flood
Less than 15 m		• Hydrostatic pressure • Earth pressure • Debris-flow hydro force	• Hydrostatic pressure
Over 15m	• Hydrostatic pressure • Earth pressure • Uplift force • Inertial force during earthquake • Dynamic water pressure during earthquake	• Hydrostatic pressure • Earth pressure • Uplift force • Debris-flow hydro force	• Hydrostatic pressure • Earth pressure • Uplift force

1.3.4 Design of Foundation

(1) Height of Sabo Dam

a) Concrete Sabo Dam

The height of a sabo dam is based on the Sabo Arrangement Plan or Master Plan. However, the foundations of a dam, especially where the height of the dam exceeds 15 meters, should be determined in consideration of the bearing capacity and permeability of the foundation rock. When the dam foundation conditions are poor, foundation treatment should be considered.

The height from the base of the dam to the crown of the overflow section (dam height) should be determined by considering the ground conditions, the proposed sediment discharge and the purpose of the dam.

b) Gabion Sabo Dam

The height of gabion dams should be less than 5m. The dams which are more than 5 m can be installed, but they will be deformed.

(2) Embedment Depth of Foundation

In principle, the dam should be located on rock foundation.

a) The depth of embedment (D) should follow the standard values below.

(i) In case of sand and gravel (ii) In case of rock

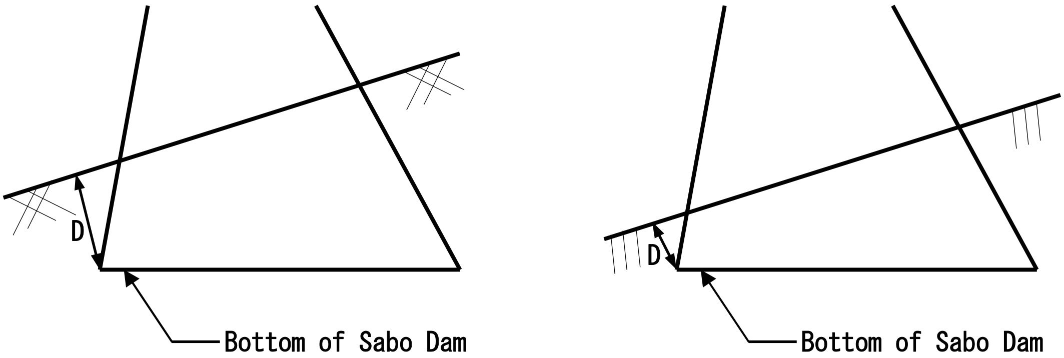


Figure 1.3.3 Depth of Embedment of Foundation

Ground Materials		Minimum Depth of Embedment(D)
Sand and Gravel		At least 2 m
Rock	Soft Rock	2 m
	Hard Rock	1 m

b) It is recommended to plan the cutoff method as shown in the drawing when the gradient is very steep.

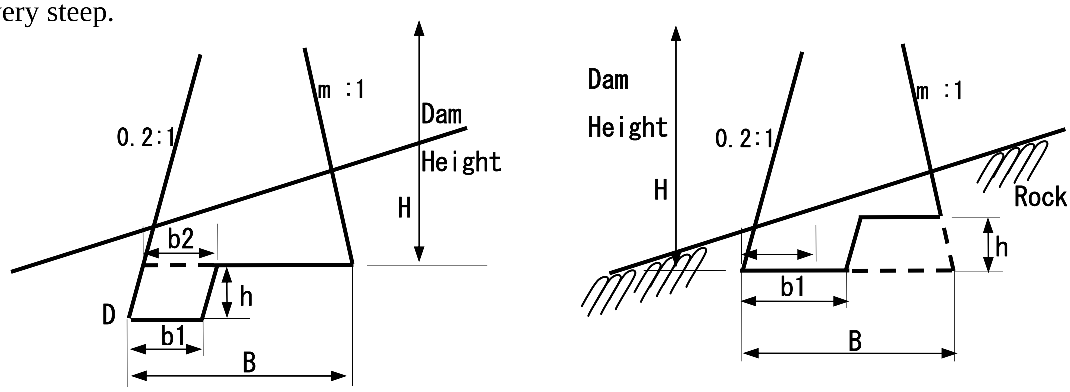


Figure 1.3.4 Cut-Off Method of Foundation

Purpose	h	B1	b2
Necessity of longitudinal planning	Below 2 m	2 m	B/3
Prevention of downstream erosion	1 m	2 m	B/3

Purpose	h	b1
Economical body of sabo dam (Rock)	At least 0.5 m	at least B/2

The embedment depth of a sabo dam is in principle more than 1.0 m in a case of bedrock and more than 2.0 m in sand and gravel foundations. Cut-off method should be implemented at the toe of dam to prevent damage by scouring. In addition, gabions should be installed in front of sabo dam (downstream side) to prevent overturning attributable to erosion of riverbed. As this countermeasure, gabions should be installed same as the height of the dam in length. The cut-off wall height will be neglected in stability calculation. The methods of foundation treatment are improvement of subgrade bearing capacity and shear sliding resistance force. As the other methods of improvement of foundation treatment, against the piping, in case of lack of the length of penetration pathway, the width of base of dam should be widened, or cut-off wall should be implemented.

1.3.5 Design of Downstream Protection Work

Erosion protection work at right downstream of sabo dam should be designed as so to minimize the scour of the foundation ground or riverbed erosion below the sabo dam due to water, sand and gravel flowing from the sabo dam.

It is suggested that gabion mattress be used to prevent foundation scour from flowing water and debris flow. The length of downstream protection work along the riverbed shall be 2.0 to 5.0 m depending upon the height of dam and the soil properties of the riverbed deposits, as follows:

Dam height (H) and Soil properties	Length (L) of protection work
H ≦ 5.0m or Riverbed deposit is not susceptible to erosion	L = 2.0 to 3.0 m
H ≧ 5.0m or Riverbed deposit is susceptible to erosion	L = 5.0 m or more

In addition, between gabion mattress and riverbed, geotextile sheet or similar material should be placed to prevent washout of fine material due to flowing water.

1.4 Consideration for Construction of Sabo Dams

The foundation works for sabo dams should be considered as follows:

a) The bearing ground should be excavated to a depth required for placing a footing if it is bedrock, the excavated foundation surface of bedrock should be cleaned, and then the spread footing should be placed.

b) If the bearing ground is earth or gravel, rubblestones should be laid over the excavated surface and rolled fully and uniformly, leveling concrete should be poured over the rubblestones, and then the spread foundation should be placed over it.

c) If the bearing ground is slanted, the portion at the valley side should be excavated in the form of steps and the rock should be replaced with concrete to the bedrock line to form a horizontal, uniform foundation. After this, the body of retaining walls or sabo dams should be directly constructed over the foundation.

d) If the bearing ground is soft and compressible, a pile foundation should generally be applied. In addition, if the soft ground (or stratum) is thin or if replacing material is easily available, the soft ground should be replaced with good quality soils so that the retaining walls may be built directly over the replaced material.

e) Timber piles, for example, 80 to 100 mm in diameter, 2.0 m to 3.0 m long, may be installed on gabion walls at longitudinal spacing of 3 to 4.0 meters to prevent the deformation of the gabion from the earth pressure of the back slope.

1.5 Design of Box Culvert

(1) Design discharge

The method is same as that of determining the discharge of sabo dam.

(2) Design cross section for design discharge

The formulation of Manning is used as follow,

$$Q = V \cdot A \qquad (1.5)$$

$$V = 1/n \cdot R^{2/3} \cdot I^{1/2} \qquad (1.6)$$

Where,

Q (m^3/sec) = Design discharge

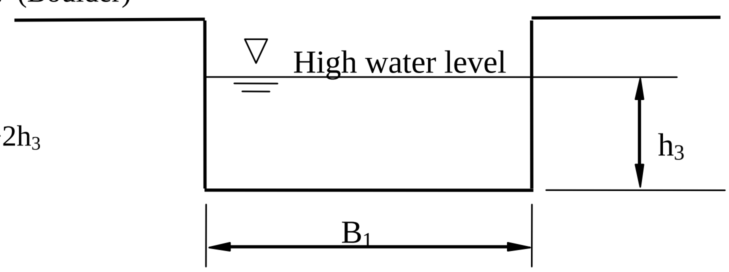
A (m^2) = Cross-section area of flow; $A = h_3 \cdot B_1$

V (m/sec) = Velocity of flow

n = Roughness coefficient (ordinarily used is shown below)

Mountainous stream: 0.03~0.05 (Gravel, cobble)

: 0.04~0.07 (Boulder)



R (m) = A/P = Hydraulic radius

P (m) = Wetted perimeter; $P = B_1 + 2h_3$

I = Slope of stream bed

B_1 (m) = Base width of Channel

h3 (m) = Depth of design flood discharge

m_2= Side slope of opening

It is recommended to check the cross section of existing box culvert applying designing method described above. B1 and h3 should be checked at the sight, and calculate Q (discharge). If present cross section is too small to flow down the design discharge, according to the priority, the box culvert should be re-designed, and implemented. Before implementation, debris, gravels, and boulders should be removed.

CHAPTER 2

INTRODUCTION OF SABO SOIL CEMENT

2.1 General

Sabo soil cement is a recently developed sabo construction technology, which is developed for effectively utilize the site-generated soil for constructing sabo facilities. The sabo soil cement is an intermediate material between concrete material and soil material.

The methods or structures utilizing sabo soil cement generally achieve the following advantage over existing methods:

a) Reduced amount of construction spoil soils

b) Improved safety of facilities

c) Cost reduction

d) Short construction time

e) Contribution to the recycling-based society

The methods utilizing sabo soil cement can be classified, in terms of execution method, into two categories, namely, In-situ Stabilized Excavation Material (INSEM) method and In-Situ Mixture (ISM) method, as shown in Figure 2.1.1.

The former intends to build structures by mixing site-generated soil with cement and compacting with vibrating roller. Before 2000 year, three methods, Sabo CSG (Cemented Sand and Gravel) method, INSEM method and CSG method were developed by three different organizations, respectively. The three methods are basically the same and standardized as the INSEM.

On the other hand, the latter intends to construct structures with the specified strength by backfilling the site-generated soil with large cobbles removed from excavated soil, and agitating and mixing with cement milk.

As shown in Figure 2.1.1, what basically differ is the use of twin header for the ISM method and the use of vibrating rollers for the INSEM, respectively.

Taking account of availability of construction equipment at present in Nepal, this chapter only introduces the INSEM method, including its applicability, design consideration and construction procedure.

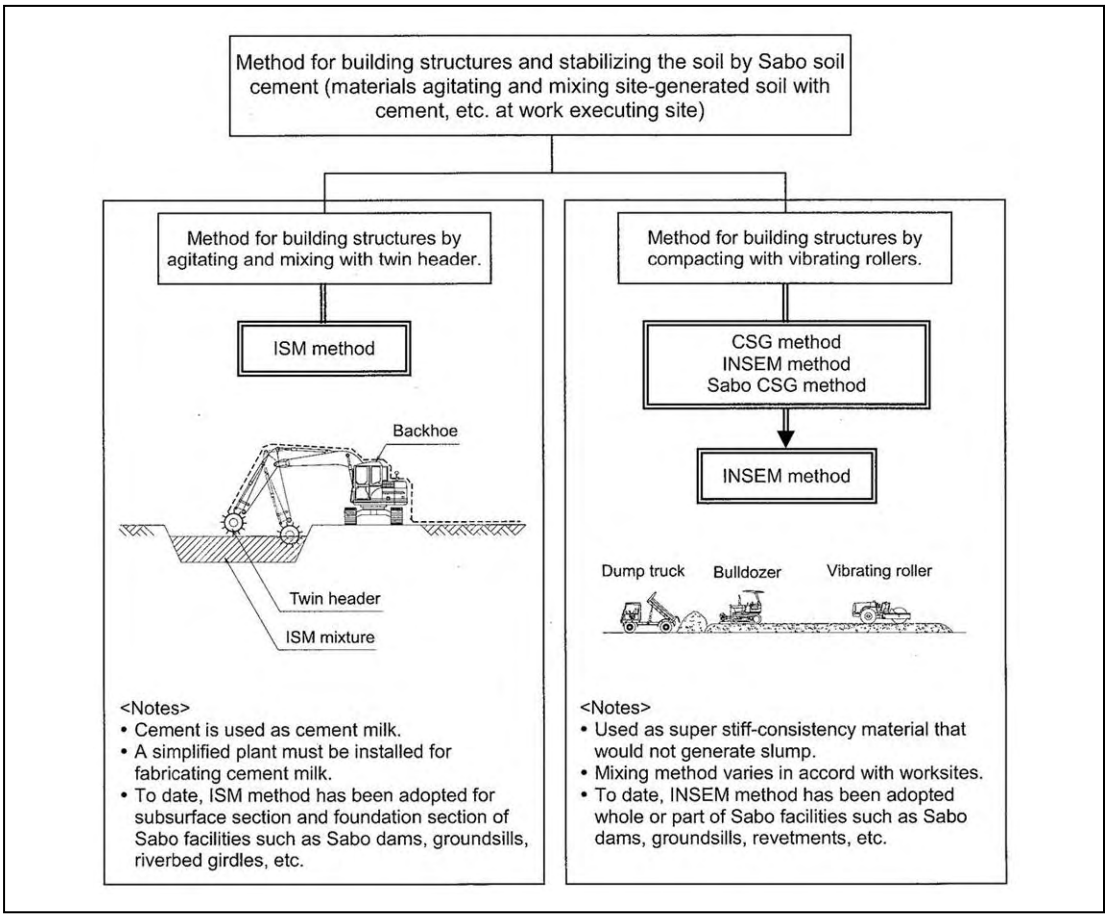


Figure 2.1.1 Classification of Methods Utilizing Sabo Soil Cement

In Nepal, sabo facilities, especially sabo dams are generally constructed either with gabion or with concrete. As we know, concrete sabo dams have high quality and strength, but cost high and take a long construction time. On the other hand, gabion sabo dams have a low resistance to earth pressure and debris flow erosion. Therefore, sabo soil cement, especially in sabo facilities is introduced to generate an intermediate structure between concrete and gabion structures and is expected to accomplish the following targets:

a) High strength sabo structures with lower cost

b) Effective utilization of excavated gravel materials at execution site and promotion of resources recycling-based society.

In addition, data and information in this chapter is mainly based on “Utilization Guidelines for Sabo Soil Cement”, Prepared by Kajima Institute Publishing Co., Ltd and published by Green Belt Co., Ltd., May 2002.

2.2 Characteristics and Applicability of Sabo Soil Cement

2.2.1 Applicability

Figure 2.2.1 conceptually shows its position with soil material and concrete material, while Figure 2.2.2 gives the applicability of Sabo soil cement, which has a wide application by setting appropriate mix proportion according to application objectives.

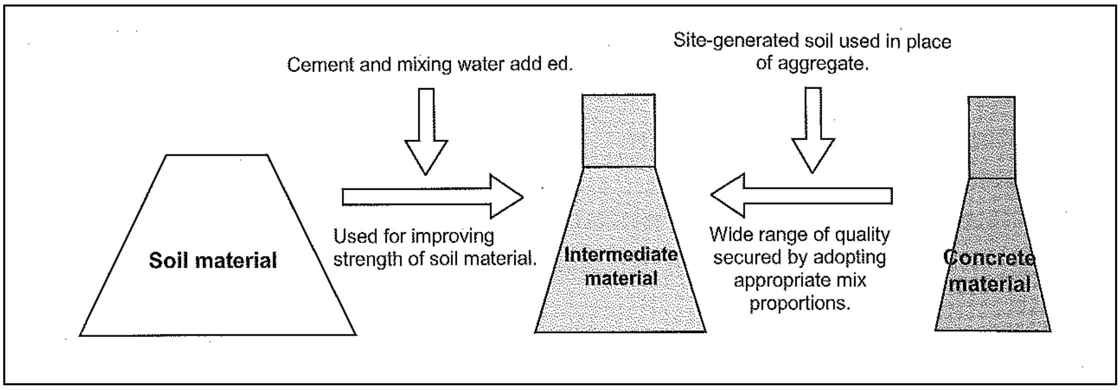


Figure 2.2.1 Schematic Drawing of Sabo Soil Cement

Material classification		Site-generated soil	Sabo soil cement	Concrete
Applicable facilities, portions etc	Embankment	←	→	
	Subbase	←	→	
	Filling		←	→
	Artificial bank		←	→
	Structure foundation		←	→
	Structure inside Underground portion		←	→
	Structure outside Surface section		←	→
	Sabo dam Dam crest			←→

Figure 2.2.2 Applicability of Sabo Soil Cement in Sabo Facilities and Others

2.2.2 Characteristics

In comparison with concrete material, Sabo soil cement has the following advantages or characteristics:

a) Reduced amount of construction soil, including excavated materials

b) Improved safety of construction

c) Reduced construction cost

d) Beneficial to recycling-based society

On the other hand, when compared to soil material, it has also the following advantages:

a) Increased strength of structures

b) Reduced cross section and volume

c) Effective application of site-generated soil

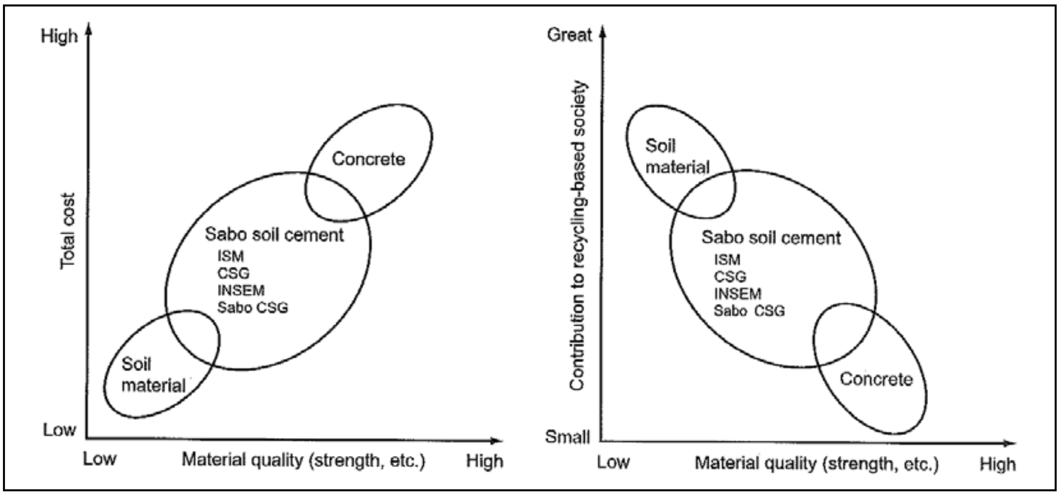


Figure 2.2.3 Schematic Illustration of Material Quality and Advantages of Sabo Soil Cement

2.2.3 Material Used

Sabo soil cement shall mainly comprise site-generated soil, cement and cement milk, by which a sabo work is constructed at the work execution site.

(1) Site-generated soil

a) The quality of Sabo soil cement shall only be confirmed by mix test.

b) In the case of INSEM, the maximum size of soil-generated soil is required to be less than a half of the screeded layer thickness.

(2) Water and Cement

a) At work execution site, any kind of water that shall not prevent cement hardening reaction can be used, including running water, etc. In the case of INSEM, no or only a small amount of water is generally added.

b) In sabo work, blast-furnace cement (class B) with excellent long-term strength and chemical resistance is preferably used.

2.3 Design

The INSEM method is applied to effectively utilize excavates soil or surplus materials for constructing the planned structures. It is thus required to understand how much soil is generated and how much gravels (about 80 mm in diameter and less) excluding large gravels are available at execution site. The planned structures shall be constructed by incorporating how and where and with what functions the INSEM method should be used.

2.3.1 Design Procedures

With respect to sabo facility, structures using the INSEM method should be generally designed according to the following procedure:

a) Determination of basic cross sectional profile according to the conditions and the equanimity and quality of the site-generated soil taken into account. This step shall judge whether it is feasible to use the INSEM for sabo structures.

b) Determination of standard of desired strength level

c) Structural stability analysis

d) Determination of external protective thickness

2.3.2 Design Parameters

(1) Unit weight

In general, the unit weight of sabo soil cement is between 1.95 and 2.05 t/m^3 in the dry condition and between about 2.15 and 2.25 t/m^3 in the wet condition.

For the purpose of stability analysis of structures, the unit weight of sabo soil cement should be determined according to the results of compaction test and mix test. In general, 90% to 95% of the unit weight of mix tests standard specimens is adopted for stability analysis.

(2) Desired strength

The quality of sabo soil cement shall be generally evaluated by compressive strength. In the case of the INSEM method, a surficial safe desired strength must be established with respect to the maximum compressive stress generated inside the structures. Therefore, the lower limit of the desired strength should meet with the following relationship:

- Desired strength ≧ Maximum compressive stress × Safety factor (n)

The safety factor in the case of the INSEM is generally set to be 4.0.

The age for the desired strength shall be normally 28 days. And the desired strength is subdivided into 6 levels in terms of required structure performance, as shown in table below.

Desired strength (N/mm^2)		Required performance	Unit cement content (kg/m^3)
Level I	0.5 – 1.5	Quality as filling and stabilizing materials	Under 60kg/m^3
Level II	1.5 – 3.0	Quality as stabilizing material and foundation work	60-80kg/m^3
Level III	3.0 – 6.0	Receptivity against internal stress	80-200kg/m^3
Level IV	6.0 – 18.0	Receptivity against several times of freezing and thawing	
Level V	18.0 – 21.0	Freezing and thawing resistance	
Level VI	Over 21.0	Abrasion resistance	Over 200kg/m^3

Notes：Unit cement content was referred to the case in Japan.

Figures 2.3.1 to 2.3.4 show sabo soil cement application respect to desired strength levels.

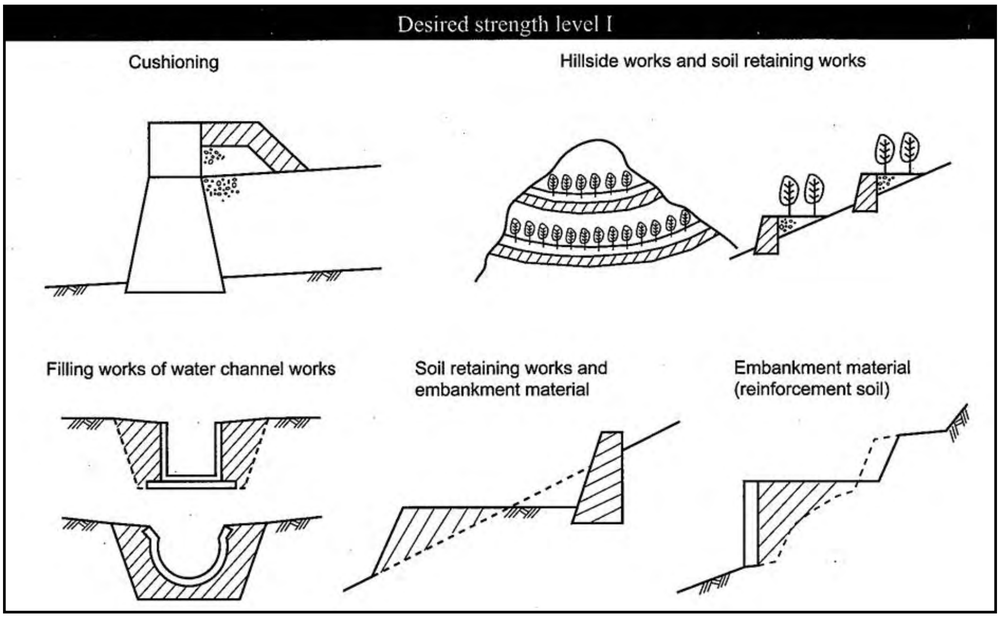


Figure 2.3.1 Schematic View of Sabo Soil Cement (Level I)

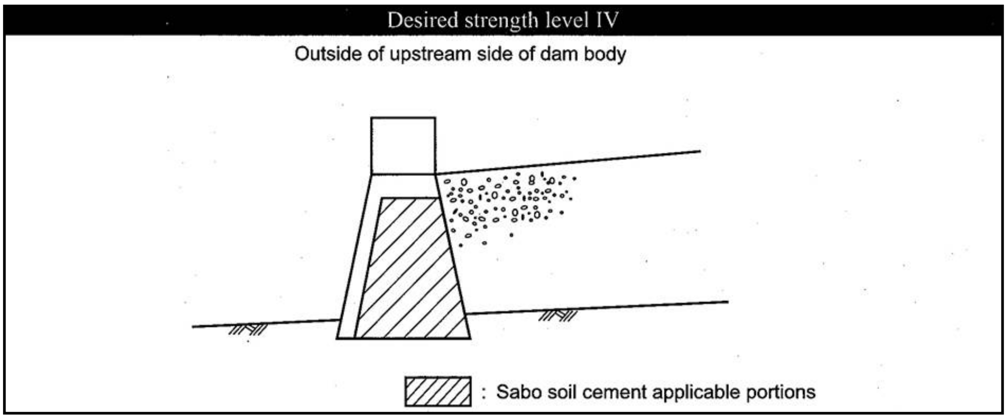


Figure 2.3.2 Schematic View of Sabo Soil Cement (Level IV)

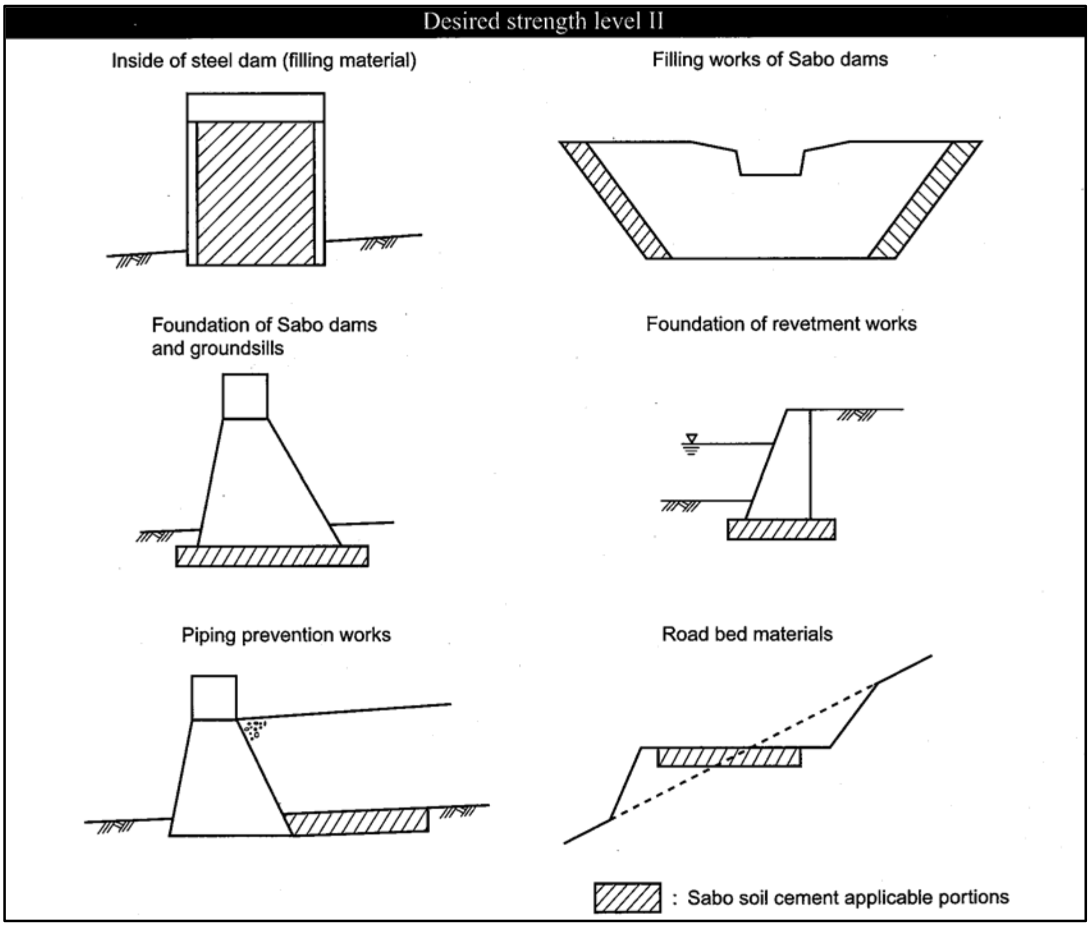


Figure 2.3.3 Schematic View of Sabo Soil Cement (Level II)

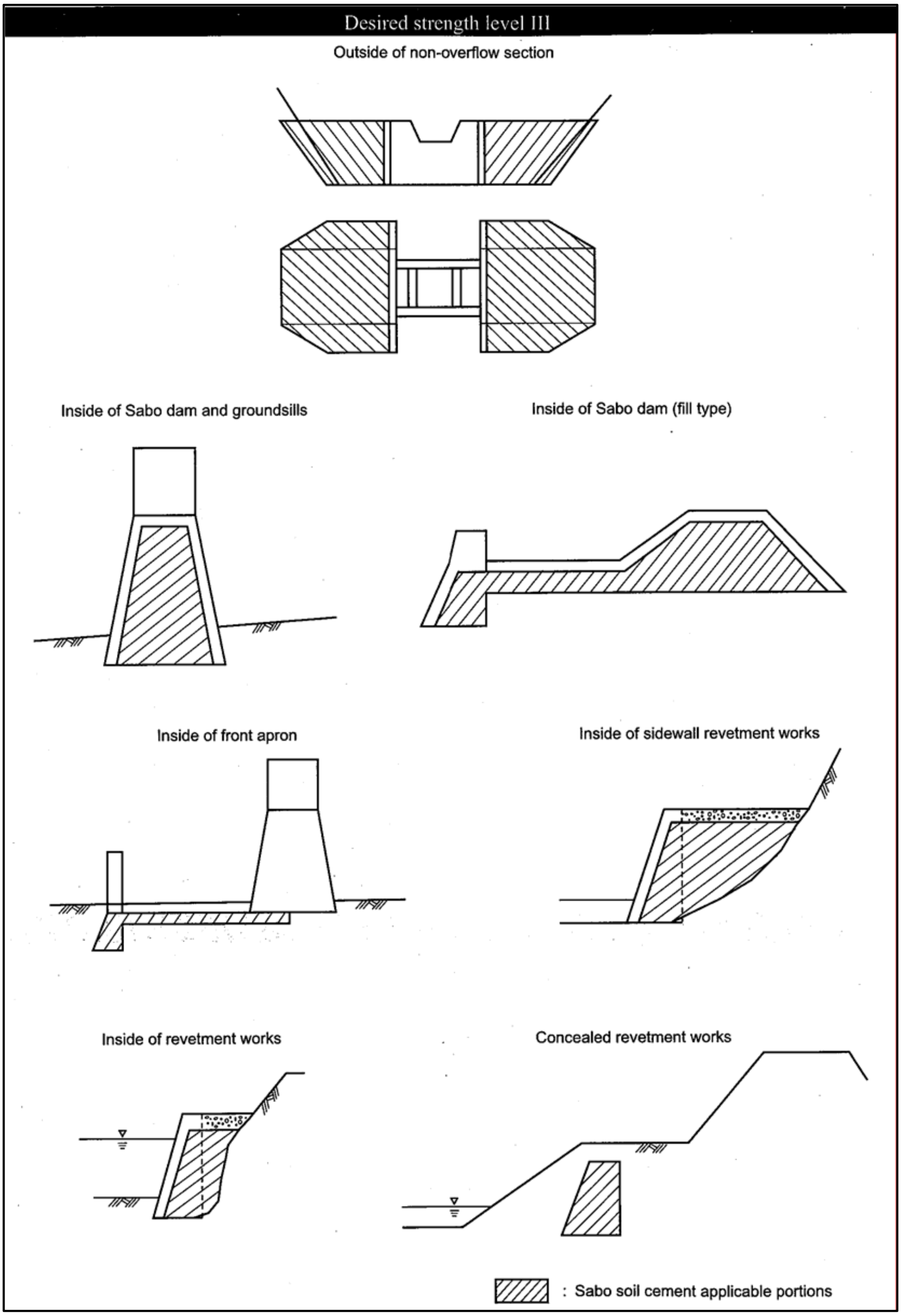


Figure 2.3.4 Schematic View of Sabo Soil Cement (Level III)

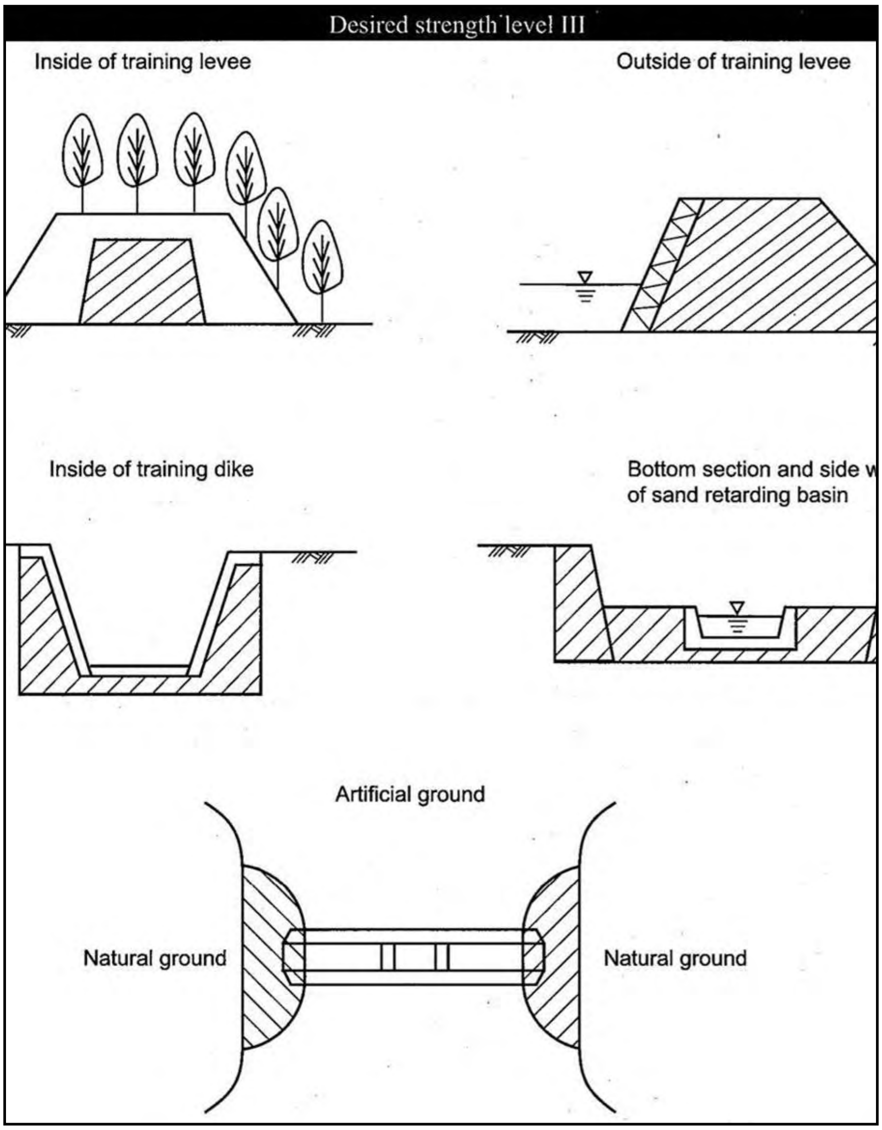


Figure 2.3.5 Schematic View of Sabo Soil Cement (Level III)

2.3.3 Structural Calculations

Structures built with Sabo soil cement shall be designed to achieve stability against overturning, sliding, and subgrade reaction, basically similar to the case of designing regular gravity system Sabo facilities.

The stability analysis refers to Chapter 1, Sabo Dam.

2.3.4 Determination of External Protective material Thickness

Of the structures applied with Sabo soil cement, portions subject to freezing and thawing action and abrasion action shall be protected with external protective materials such as concrete material, soil material, stone material, steel material, etc.

The thickness of the external protective thickness shall be properly established with the scale of the structure and conditions of the planned place taken into account. Particularly, where erosion and abrasion action are excessively exerted, such as levee crown, etc. of Sabo dams, thoroughgoing abrasion measures shall be taken. In Tarai, for example, sabo dam with sabo soil cement may be damaged, especially in the over flow portion, by the erosion and abrasion of debris flow sediments.

External protective material generally contains concrete cover, riprap work, stone pitching, etc. When concrete material is used for external protective material, the thickness should be generally 50 cm or more, as shown in Table 2.3.1.

Table 2.3.1 Good-rule-of-thumb for external protective material thickness

・In the case of small-scale structures	・In the case of large-scale structures ・In the case of structures susceptible to particularly violent meteorological action and abrasion action
50 cm or more	100 cm or more

Figure 2.3.6 shows an example of Sabo dam using sabo soil cement, which is protected by riprap work.

Figure 2.3.6 Sabo Dam of Sabo Soil Cement Covered by Riprap Work (Genbu Sabo dam, Iwate Prefecture, Japan)

2.4 Execution with INSEM Method

2.4.1 Execution Procedures

Figure 2.4.1 shows the standard work execution procedures and machinery used for the INSEM method.

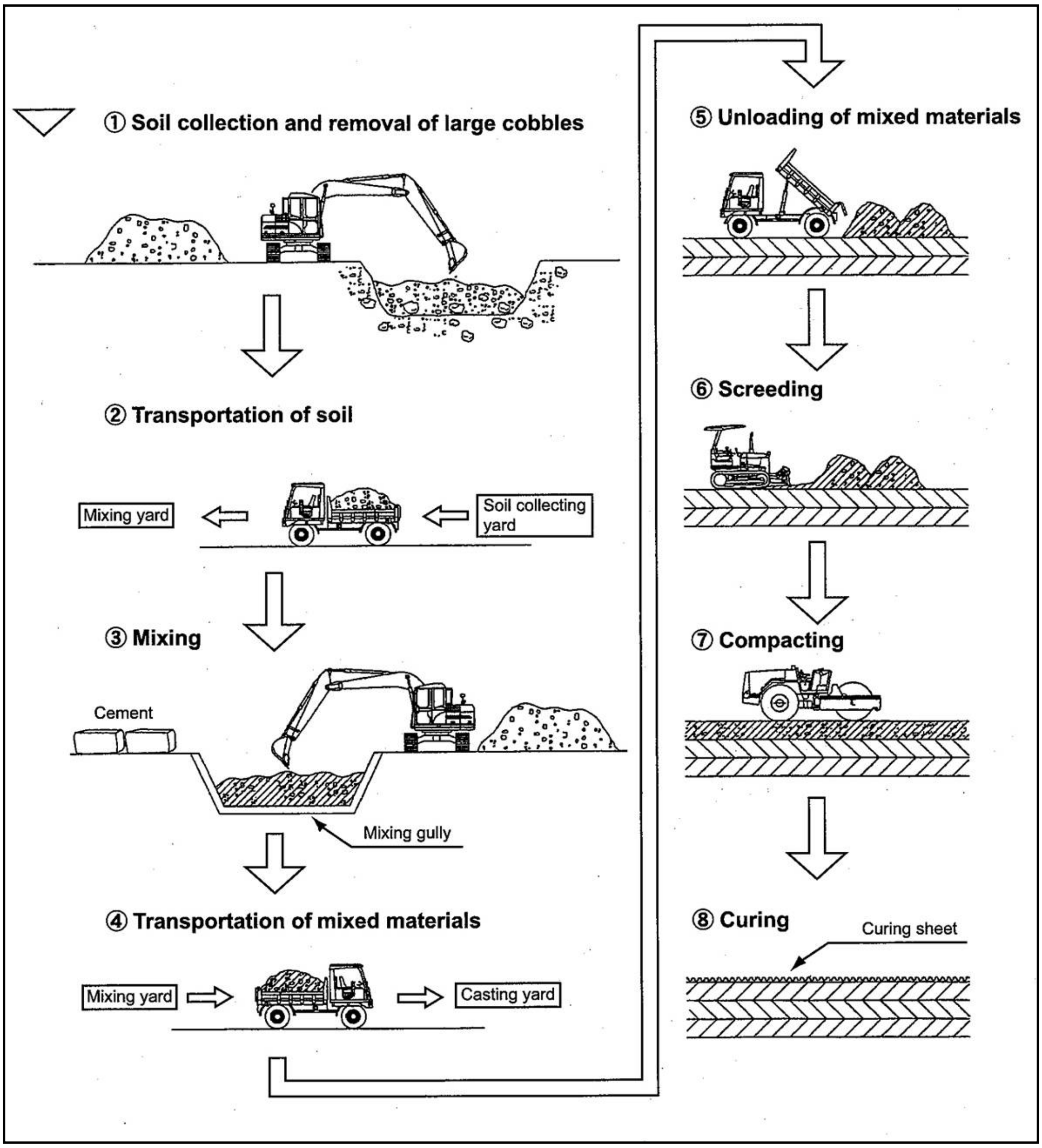


Figure 2.4.1 Standard work execution procedure of INSEM method

2.4.2 Selection of Construction Equipment

When using the INSEM method, selection of the mixing machines and compacting machines is more important, and consideration should be given to the following points:

a) Workability

b) Market availability

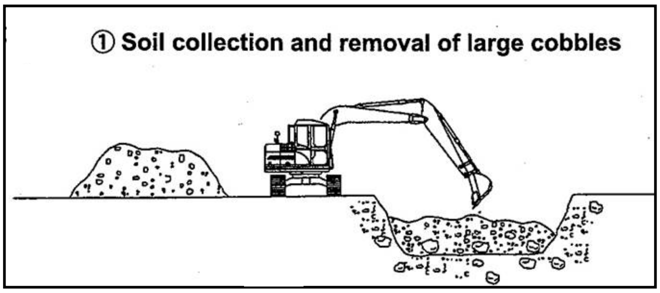
c) Mixing performance (quality of mixed condition)

d) Work execution conditions

In Japan, backhoes are normally selected for mixing machines because of their superb market availability and versatility and outstanding workability and economy. On the other hand, vibrating roller is used as compacting machines. In addition, a large-size vibrating roller can be used to compact a thicker layer and to improve the workability. A small-size vibrating roller, if available, can be also used, but the compacted layer thickness should be reduced to meet its capacity.

The following shows some actual used equipment for each execution step shown in Figure 2.4.1.

① Soil collection and removal of large cobbles

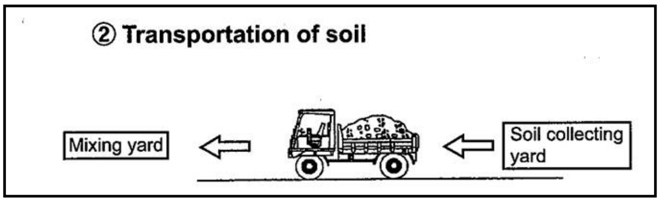


- Soil collection : Backhoe
- Removal of large cobbles : Backhoe with skeleton bucket, grizzly bar

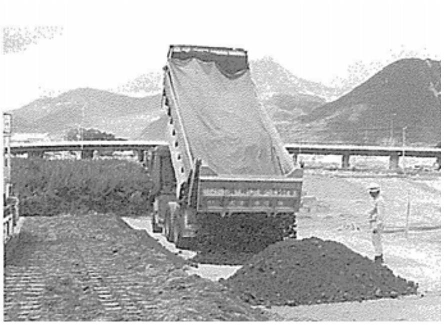
Skeleton bucket

Grizzly bar

② Transportation of Soil



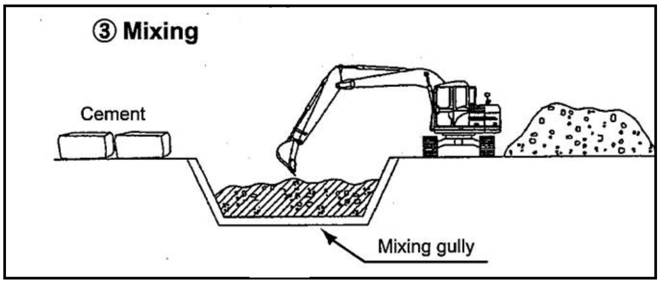
- Machine used: Dump truck, Crawler dump truck, Backhoe



Dump truck

Crawler dump truck

③ Mixing

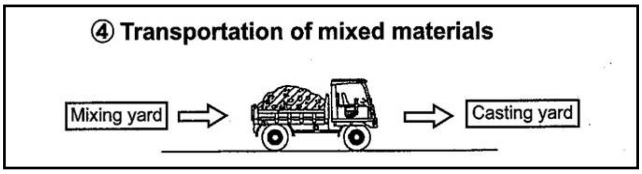


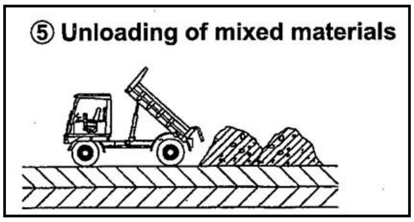
- Machine used: Backhoe, Agitator car, Batcher plant etc.

Backhoe

Agitator car

④ Transportation of mixed materials and unloading of mixed material





- Machine used: Backhoe, Agitator car, Batcher plant etc.

⑤ Construction joint treatment

1) Dry cement sprinkling

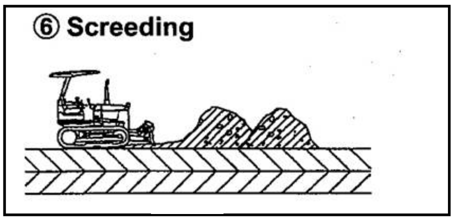
2) Cleaning and water sprinkling only on concrete-cast surface

(For portions with large cross section or when adhesion can be achieved without carrying out construction joint treatment)

Cleaning and water sprinkling

Dry cement sprinkling

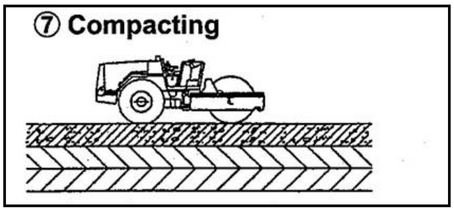
⑥ Screeding



- Machine used: Bulldozer, Backhoe

Screeding using bulldozer

⑦ Compacting



- Machine used: Vibrating roller, Hand-guide type vibrating roller, Vibrating tamper

Compaction with vibrating roller (surface compaction)

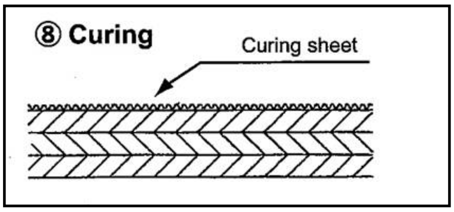
Hand-guide type vibrating roller Vibrating tamper

Table 2.4.1 indicates vibrating rollers by standard and reference compacted layer thickness

Table 2.4.1 Vibrating Roller and Standard Compacted Layer Thickness

Vibrating roller	Compacted layer thickness
10t class vibrating rollers	About 50 cm
3t to 5t vibrating rollers	30 cm or less

⑧ Curing



1) Curing sheet + curing mat, water sprinkling
2) Same curing as general concrete

Sheet curing condition

2.4.3 Control item at execution

(1) Control item

Process control, quality control, work progress control, and photograph control shall be carried out at appropriate frequency in order to secure and verify the quality and amount of work completed of Sabo facilities and soil stabilizing material.

(2) Process control

Feasibility studies shall be carried out before ground breaking and process control shall be implemented so that the works based on the method making the best of Sabo soil cement would take place smoothly.

(3) Quality control

The quality of site-generated soil used for soil cement and the quality of Sabo soil cement shall be measured and controlled at appropriate frequencies by various tests.

Table 2.4.2 shows the draft main quality control criteria in the INSEM method.

Table 2.4.2 Draft Quality Control Standard in INSEM Method

Test item		Test frequency	Remarks
Site-generated material	Sieving	About once/week	JIS A 1102、1204
	Density, water absorption		JIS A 1109、1110
	Moisture percentage	Once/day	Frying Pan method
Admixture	Spraying of phenolphthalein	Once/day	Visual
	Compressive strength	Once/day	Age: 7 days, 28 days

(3) Work progress control

The work progress control in the construction method utilizing Sabo soil cement shall be carried out in conformity to the work progress control items and standard values with features of the work execution method taken into account.

CHAPTER 3

CUT SLOPES

3.1 General

Cutting work is one of the most frequent and useful methods in road construction and stabilization of unstable slopes.

Along the N-M highway, a lot of cut slopes were formed due to road excavation. Since the 2003 disaster, these cut slopes are the main sites of slope failures, potential slope failures or landslides, and rock fall. The main problems relating to the cut slopes are summarized as follows:

a) These cut slopes are formed mostly with a steeper gradient than the standard gradient. The stabilization structures are mainly retaining walls, including gabion wall, stone masonry, and concrete wall, which are not strong enough to cope with instability. This is one of the main causes that some deformation on these structures is repeatedly formed.

b) These cut slopes are mostly protected with vegetation or using structures, except for local treatment with retaining walls. For example, Location 23km+510 (LS-2), Location 23km+960 (LS-3) and Location 30km+690, because of no cover after cutting, erosion due to surface water and spring has been active and shallow collapses on the foot of the cut slopes have been triggered. In the worst case, large-scale slope failure or landslide would be initiated where these shallow collapses are in progress.

c) No berms were provided on the long cut slopes.

d) No surface drainage ditches were provided inside and around the cut slopes; this may facilitate surface water to erode the cut slopes, especially soil cut slopes.

3.2 Gradient and Shape of Cut Slopes

3.2.1 Standard Gradient

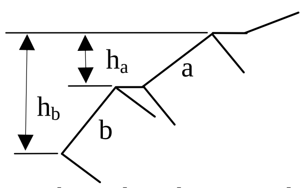
A stable cut slope should generally be designed according to the standard values of the gradient of slopes, as listed in Table 3.2.1.

The standard values of the gradient of slopes, as shown in Table 3.2.1 have been empirically determined on the basis of geological conditions and at the standard values cut slopes remain stable over the long-term with simple slope protection works such as vegetation.

Table 3.2.1 Geometric Standards for Cut Slopes

Character of soil or bedrock		Cut slope height (m)	Gradient (i=V:H)
Hard rock			1:0.3 ~ 1:0.8
Soft rock			1:0.5 ~ 1:1.2
Sand	Sand that is not solid or dense and has poor grade distribution.		1:1.5 ~
Sandy soil	Soil that is dense and solid.	Less than 5 m	1:0.8 ~ 1:1.0
		5~10 m	1:1.0 ~ 1:1.2
	Soil that is not dense and solid.	Less than 5 m	1:1.0 ~ 1:1.2
		5~10 m	1:1.2 ~ 1:1.5
Sandy soil mixed with gravel or rock	Soils that are dense and solid or of good grade distribution.	Less than 10 m	1:0.8 ~ 1:1.0
		10~15 m	1:1.0 ~ 1:1.2
	Soils that are not dense or solid or are of bad grade distribution.	Less than 10 m	1:1.0 ~ 1:1.2
		10~15 m	1:1.2 ~ 1:1.5
Cohesive soil		Less than 10 m	1:0.8 ~ 1:1.2
Cohesive soil mixed with rock or cobble stones		Less than 5 m	1:1.0 ~ 1:1.2
		5~10 m	1:1.2 ~ 1:1.5

Notes: (1) Silt is included in the category of cohesive soil.
(2) Individual consideration is given to soils not indicated in the above table.
(3) When a single gradient can not opted for because of the soil composition or other reasons, the cut slope height and gradient are determined on the basis of the following considerations.



h_a: Cut slope height for slope surface a

h_b: Cut slope height for slope surface b equals the height of a plus the height of b

- The gradient does not include a berm.
- The cut slope height vis-à-vis the gradient means the total cut slope height including all the cut slopes above the cut slope in question.

Source: Modified from Highway Earthwork Series, MANUAL FOR SLOPE PROTECTION, Published by Japan Road Association, March 1999.

As shown in Table 3.2.1, the gradient of cut slopes varies depending on the geology of the cut slope. Where the geology and soil of a cut slope varies considerably and is complicated, a single gradient of cut slope suited to weaker soil is used even though this is somewhat uneconomical. Figure 3.2.1 gives a schematic diagram of a cut slope relating to different geology.

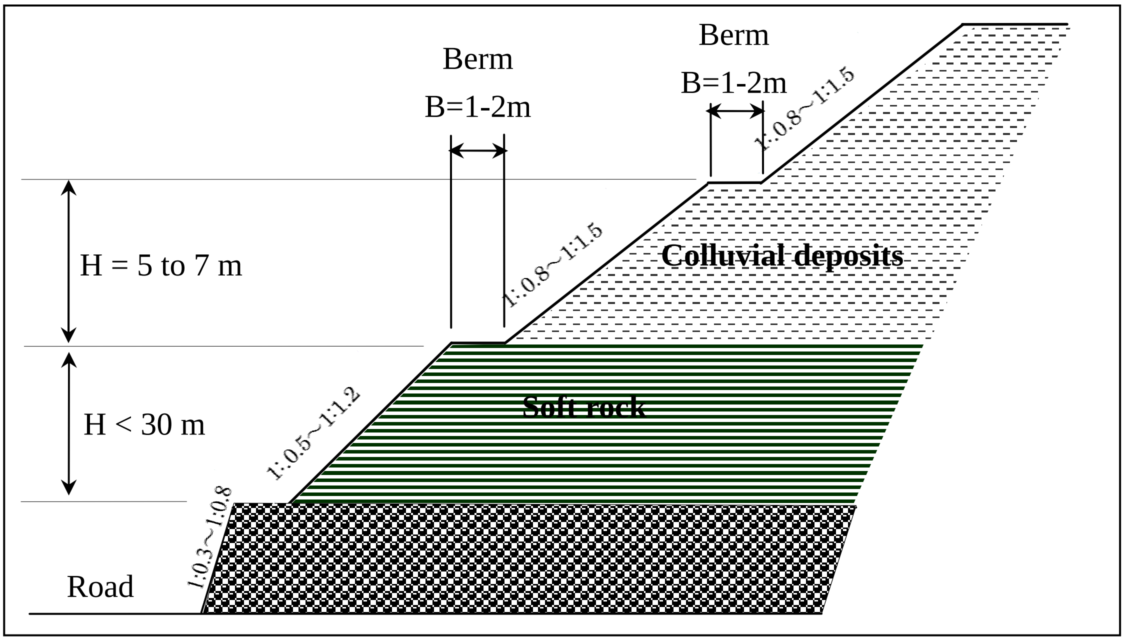


Figure 3.2.1 Conceptual Illustration of a Cut Slope

3.2.2 Berms

On cut slopes, berms 1.0 to 2.0 m wide should generally be provided for every 5.0 to 7.0 m in height for the following purposes:

a) To reduce speed of the surface water flow on the cut slopes, thereby decreasing scouring force on the cut slopes;

b) To provide a place for the installation of drainage ditches; and

c) To be used as sidewalk for inspection or as scaffolding for repair works.

A wider berm is recommended where the slope is long and large or where rock fall protection fences are to be installed.

3.2.3 Rounding

For protecting cut slope from surface erosion, especially rainfall water, the cut slope shall have a gentle and rounded finish at the top and at both ends.

The top of slope is the main sites of local slope failures because it is easily eroded and vegetation can hardly grow. Round shaping should thus be provided to prevent it from erosion and subsequent collapse, as shown in Figure 3.2.2.

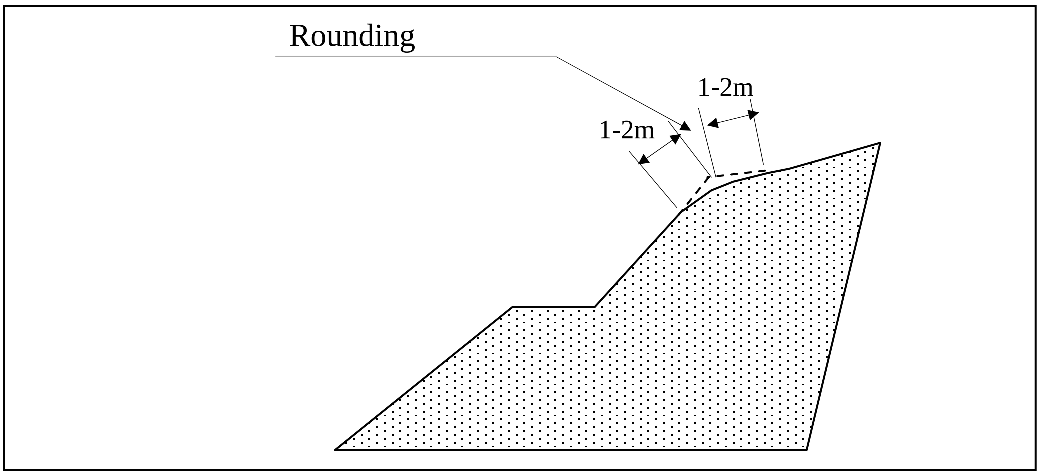


Figure 3.2.2 Rounding at Top of Cut Slope

3.3 Protection of Cut Slopes

To prevent erosion subsequent to cutting, protection for the foot of the slope as well as for the cut slope itself should be considered and provided. When it is unavoidable to form a cut slope with a gradient steeper than the standard gradient, the slope must be protected by a retaining wall or anchor works.

Protection works are generally classified into two groups, in terms of slope geology, topographical conditions, regional rainfall, cut slope shape, etc., as follows:

a) When the cut slopes are designed with standard gradients, the cut slope protection works will be vegetation, pitching (stone, concrete block) work, mortar or concrete spraying work, shotcrete crib work. Vegetation works are always the preferred option if possible. Otherwise, the other protection works should be used when vegetation is not suitable due to steeper slopes or rock slopes. The above works are essentially capable of withstanding earth pressure. If there is a hazard of facing earth pressure a different type of works, as described in the following Section, shall be required.

b) When the cut slopes are designed with a gradient steeper than the standard gradient, the cut slope must be stabilized by structures of preventive force, such as retaining walls, rock bolt works, rock bolt work with crib work, and anchor work with crib work. The selection of the works will be based mainly on the necessary preventive force. The detailed requirements for their design will be described in the following separate chapter.

Slope protection works should be immediately followed with the completion of cut slope. In planning and executing a slope protection works, special attention should be paid to the following points:

a) It is generally difficult to accurately predict the ground condition prior to excavation. Therefore, if the actual ground condition after excavation is considerably different from the assumptions at design stage, the suitable of planned slope protection work should be carefully examined again.

b) In the case of a long and wide cut slope, it is desirable to execute protection work in line with the progress of excavation without waiting for the completion of excavation.

c) When the cut slopes are protected by structures, especially such as mortar and concrete spraying, pitching and shotcrete, the implementation of spring water control and drainage is required.

Prior to structural slope protection works, such as mortar spraying work and crib work, unstable rock blocks, dust, unwanted sediments should be removed from the face of the slope to prevent the detaching, unevenness or cavities behind the executed structures.

3.4 Cutting Work as Stabilization of Unstable Slopes

As stated before, cut slope or cutting (earth removal) work is applied to remove unstable landslide mass as well as potential slope failures and to reduce the load, and hence driving force at the head of a landslide area

3.4.1 Stability Analysis

Stability analysis should be conducted to determine the scale and quantity of landslide countermeasure works required to maintain the stability of the landslide slope and so ensure the target safety factor. The Swedish slice method (also called ordinary slice method) is used for stability analysis of a landslide slope, as follows:

$$Fs = \frac{(\Sigma N - \Sigma U) \times \tan\phi + C \times \Sigma L}{\Sigma T} \qquad (3.1)$$

Where,

Fs = Factor of safety

N (kN/m)= Normal force attributable to gravity of slice, N=W・cosα

T (kN/m)= Tangential force attributable to gravity of the slice, N=W・sinα

W (kN/m)= Weight of the slice

α (°) = Angle of the base of the slice to the horizontal

U (kN/m)= Pore pressure acting on the base of the slice

L（m） = Length of sliding surface acting on the slice

C (kN/m^2) = Cohesion of sliding surface

ϕ (°) = Internal friction angle of sliding surface

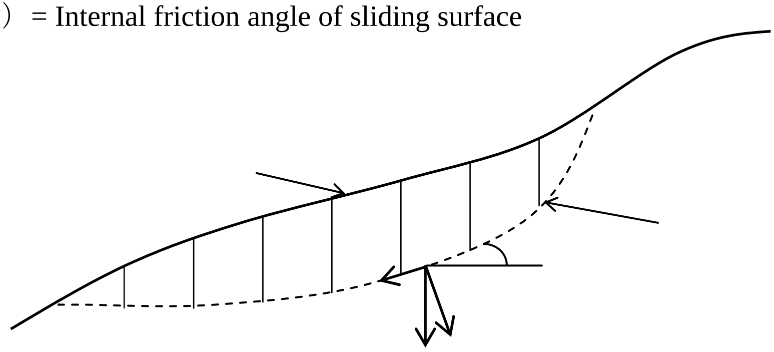


Figure 3.4.1 Conceptual Illustration for Stability Analysis

Initial value of Fs is one of the most important factors conducting stability analysis, so this value is needed to be carefully and comprehensively determined.

Initial value of Fs is set under consideration of slope condition as shown in the Table 3.4.1 which is applied in Japan.

Table 3.4.1 Initial value of Fs

State of landslide	Initial value of Fs
Obviously moving	0.95
Slightly moving related to falling rain	0.98
Almost stable	1.00

In many cases, values of soil test are not suitable for present status of landslide. So the value of C (Cohesion) is determined empirically by thickness of maximum landslide mass shown below.

Table 3.4.2 Thickness of maximum landslide mass and cohesion

Thickness of maximum landslide mass (m)	C (Cohesion; kN/m^2)
5	5
10	10
15	15
20	20
25	25

The value of ϕ is calculated by back analysis method using the value of C, and fit to the initial factor of safety. When landslide mass consists of detritus or colluvial deposit, unit weight is ordinarily used 1.8tf/m_3. Ground water level is ordinarily used in place of pore pressure.

The detail methodology shall refer to "Manual for River and Sabo Works in Japan,1997".

3.4.2 Effectiveness of Cutting Work

The effect of cutting works is evaluated mainly as a result of the reduction of the values of term N and term T in the equation of stability analysis of a slope, as follows:

$$PFs = \frac{(\Sigma(N - \Delta \mathrm{N}) - \Sigma(\mathrm{U} - \Delta \mathrm{U})) \times \tan\phi + \mathrm{C} \times \Sigma(\mathrm{L} - \Delta \mathrm{L})}{\Sigma(T - \Delta T)} \quad \cdots\cdots (4.1)$$

Where,

PFs = Proposed factor of safety (Under consideration of condition, ordinarily used is 1.05~1.20)

ΔN (kN/m)= Difference between before and after cutting works of Normal force attributable to gravity of slice, N=W・cosα

ΔT (kN/m)= Reduced tangential force after implementation attributable to gravity of the slice, N=W・sinα

ΔU (kN/m)= Reduced pore pressure acting on the base of the slice after implementation

ΔL （m） = Reduced length of sliding surface acting on the slice after implementation

Figure 3.4.2 gives the schematic diagram for cutting work related to landslides.

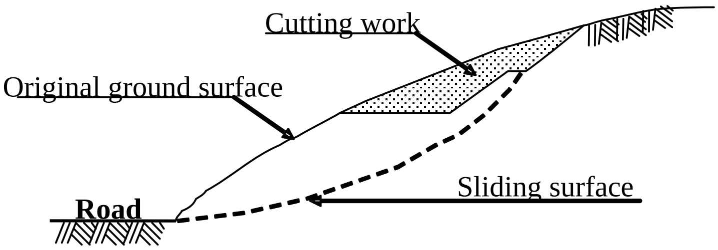


Figure 3.4.2 Conceptual Illustration of Cutting Work

Cutting works for the head part of the sliding mass where the angle of sliding surface is large will contribute to reduce driving force acting for the mass.

3.4.3 Design Considerations

In planning and designing a cutting work, special consideration should be given to the following items:

a) The work is implemented only at the head of landslide area, never at the toe;

b) The work is not applicable if the landslide is continuous;

c) The stability of the adjoining slope behind the target area should be considered ;

d) The stability of the cut slope should be considered, and vegetation covering and surface drainage should be installed on the cut slope after earth removal;

e) A combination of cutting for the head part and filling works for the toe part is more cost-effective.

3.5 Construction of Cut Slopes

As slopes are form by various types of soils and rocks generally unexpected conditions may be encountered during the cutting work. So, it is recommended to implement suitable geological surveys prior to construction. Utilizing the result of geological survey, proper judgment of measures for those unexpected situations is vital in cut slopes.

The construction of cut slopes should be carefully executed in order to ensure the stability of cut slope during and after the works.

3.5.1 Rock Cut Slopes

At first, the main portion of rocks is excavated or blasted using drilling machines such as blast hole drill or drill master, and then finishing stakes should be properly placed in order to guide and show the planned line of slopes.

To shave off rock up to the planned line of slopes, pick or coal pick hammer is used in case of soft rocks. For hard rocks, drilling along the planned line of slopes should be done with jack hammer and blasting with low power explosive may be utilized to avoid loosening of bedrocks.

After shaving off rocks, unstable rock blocks likely to fall down should be removed with pick hammer, and if difficult to remove, should be anchored to bedrocks or covered with wire net for preventing rock fall.

The unevenness on the completed surface of cut slopes should be kept to a minimum and the depth of any concave or convex portions should be as small as possible, and in the technical guide, be set to be less than 30 cm, although this may vary depending on the geological conditions of cut slopes.

3.5.2 Common Soil Cut Slopes

At the start, the main portion of the common soils is excavated with machined, leaving the soil at 20 cm to 30 cm in thickness from the planned line of cut slopes. Then, according to the placed stakes, the left common soil layers are shaved off with picks or hoes.

In general, the excavation of the main body can be completed in short time with machines. However, shaving off work should be performed in longer time.

Careful surveys on the stability of the upslope of cut slope should be conducted prior to cutting. When the potentially unstable areas, such as landslide, soil slope collapse, or rock fall above the cut sites are large, cutting should be abandoned.

In addition, the following geological conditions should be evaluated with the most care:

a) Colluvial deposit slopes. Colluvial deposits such as talus or debris materials have a low solidification and, usually form a slope with a critical angle of stability. When excavated, such cut slopes will become unstable, as shown in Figure 3.5.1. For this reason, cutting toe of colluvial deposit slope will make the slope unstable (Figure 3.5.1(a)). And cutting colluvial deposit slope equally will not improve the stability of the slope so much (Figure 3.5.1(b)).

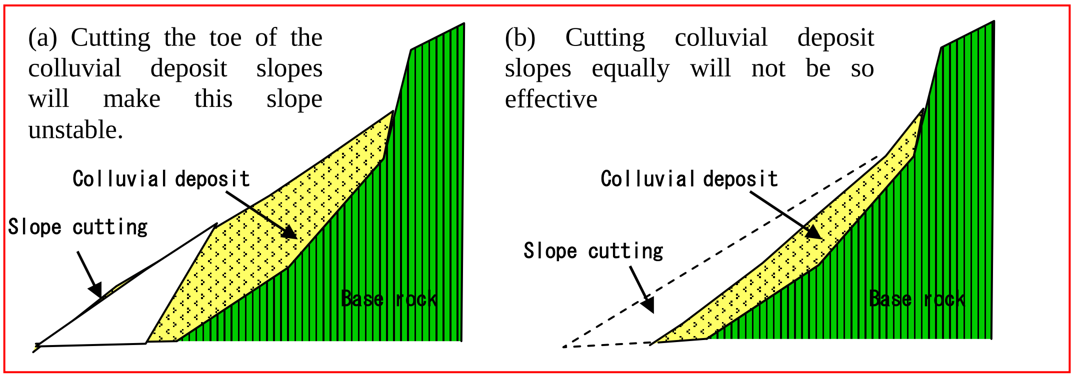


Figure 3.5.1 Cutting colluvial deposit slopes

b) Erodible sandy soil. Sandy soils such as weathered granite and terrace gravel layers are easily eroded by surface water, resulting in small shallow collapses.

c) Weatherable soft rocks. Cut slopes of soft rocks such as mudstone and tuff, will become unstable after cutting because of stress release, etc.