



Electric Power Industry Standard of the People's Republic of China

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DL/T 5045—2006  
To replace DL/T 5045—1995

Code for Design of Ash and Slag  
Damming of Fossil Fuel  
Power Plants

火力发电厂灰渣筑坝设计规范  
(英文版)

Issue Date: May 6, 2006

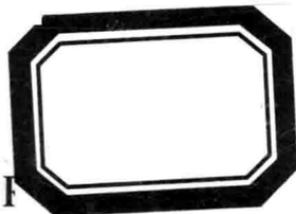
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**Code for Design of Ash and Slag  
Damming of Fossil Fuel  
Power Plants**

Translation sponsored by : China Electric Power Planning &  
Engineering Association

Translated by : SUNTHER Consulting Co., Ltd.

Reviewed by : Northeast Electric Power Design Institute

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## Foreword

This code is a revision to DL/T 5045—1995 *Technical Rules for Design of Ash and Slag Damming of Fossil Fuel Power Plants* based on the requirement of the *Notice on Issuance of Plan for Supplementing Electric Power Industry Standard 2003* issued by the *General Office of National Development and Reform Commission* (FGBGY [2003] 873) and is renamed the *Code for Design of Ash and Slag Damming of Fossil Fuel Power Plants*.

This code has played a positive role in accelerating the power construction and enhancing the design level and technical standard of ash and slag damming since its promulgation in 1995. As new requirements have come out for the design of ash and slag damming in fossil fuel power plants with the deepening of reforms and technical progress in power industry, this code is to be revised accordingly.

The main revisions and modifications are as follows:

- Following are added in accordance with the requirements of relevant codes:
- Chapter 2 “Normative References”.
- Section 6.3 “Seepage Drainage Facilities for Subdam”.
- Section 6.4 “Ash and Slag Damming by Hydraulic Filling”.
- Clause 6.5.3 “Vibro-stone Piling Method Used in Ash-slag Dam Base Treatment”.
- Chapter 10 “Requirements for Construction Quality Control”.
- Some other clauses are modified, perfected and refined.
- The relevant contents in this code are adjusted commensurate

## DL / T 5045 — 2006

with the revisions to the concerned design codes.

This code replaces DL/T 5045—1995 upon implementation.

Appendix A to this code is normative, Appendix B is informative.

This code is initiated by China Electricity Council.

This code is managed and interpreted solely by the China Electric Power Planning and Engineering Standardization Technical Committee.

This code is drafted by the Northeast Electric Power Design Institute.

The participants in drafting this code are Shandong Electric Power Engineering Consulting Institute, Shaanxi Electric Power Design Institute, and Central Southern China Electric Power Design Institute.

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This code is translated by SUNTHER Translation & Solutions under the authority of China Electric Power Planning & Engineering Association.

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## 1 Scope

This code specifies the principles and criteria that shall be followed when using ash and slag damming technique to design dam bodies in wet-type ash storage yards of coal-fired power plants.

This code is applicable not only to the design of ash dams of valley ash yards that employ hydraulic ash handling technique, but also to the design of ash embankments in ash yards on the beaches of rivers, lakes and sea (hereinafter referred to as beach ash yard) and ash yards on plains. It is not applicable to the design of dry-type ash storage yards.

The provisions specified herein for ash dams are also applicable to ash embankments, unless specifically prescribed otherwise.

## 2 Normative References

The following normative documents contain provisions which, through reference in this text, constitute provisions of this standard. For the dated references, all their subsequent amendments (excluding errors corrected) or revised editions shall not apply. However, parties who have reached agreements based on this code are encouraged to investigate the possibility of using the most recent editions of these references. For undated references, their latest editions shall apply to this code.

GB 18599 *Standard for Pollution Control on the Storage and Disposal Site for General Industrial Solid Wastes*

GB 50286 *Code for Design of Levee Project*

GB 50290 *Technical Standard for Applications of Geosynthetics*

DL 5073 *Specifications for Seismic Design of Hydraulic Structures*

DL/T 5129 *Specifications for Rolled Earth-Rockfill Dam Construction*

JTJ 213 *Code of Hydrology for Sea Harbour*

JTJ 298 *Code of Design and Construction of Breakwaters*

SDJ 280 *Technical Specifications for Electric Power Project Construction and Acceptance (Hydraulic Structures)*

SL 60 *Technical Specifications for Safety Supervision of Earth-Rock Fill Dams*

SL 237 *Specification of Soil Test*

SL 274 *Design Code for Rolled Earth-Rock Fill Dams*

### 3 Terms and Definitions

The following terms and definitions apply to this code.

#### 3.0.1

##### **Ash dam**

Hydraulic structure used to store ash and retain water in valley ash yard.

#### 3.0.2

##### **Ash embankment**

Hydraulic (marine) structure used to store ash and retain water in plain and beach ash yards.

#### 3.0.3

##### **Dam body**

Entire ash dam consisting of a primary dam, subdams and deposited ash and slag.

#### 3.0.4

##### **Primary dam**

Initial dam body when ash dam being constructed by stages.

#### 3.0.5

##### **Subdam**

Dam body heightened on top of deposited ash on dam front when ash dam being constructed by stages.

#### 3.0.6

##### **Ash and slag**

Mixture of pulverized coal ash collected by precipitators and slag discharged from bottom of boilers in a coal-fired power plants.

3.0.7

**Ash and slag damming**

A by-stage damming technique to gradually heighten dam bodies by building subdams on deposited ash on dam front with earth-rock material or ash-slag material in ash yard.

3.0.8

**Ash and slag filling-siltation damming**

Ash and slag damming by hydraulic filling.

3.0.9

**Terminal dam height**

Maximum possible dam height determined by taking into account natural topography and geological conditions of ash storage yard, requirements by power plants and other factors.

3.0.10

**Aggregate capacity**

Total volume of ash, slag and flood that can be accommodated by ash yard with terminal dam height.

3.0.11

**Length of dry bank**

Horizontal distance from the point where water surface crosses ash surface to the point where ash surface crosses upstream slope of dam on the cross-section perpendicular to dam axis.

3.0.12

**Limited length of dry bank**

The length of dry bank that can be maintained to restrict height of phreatic line and ensure safety of dam body during operation.

3.0.13

**Ash storage elevation**

Elevation where surface of ash deposited in ash storage yard

joins upstream slope of dam.

3.0.14

**Limited ash storage elevation**

Maximum ash storage elevation permitted by dam top elevation in each design stage.

3.0.15

**Subdam height**

Elevation difference between two contiguous dam tops.

3.0.16

**Subdam placement height**

Height of subdam built on deposited ash surface.

3.0.17

**Dam extra height**

Height from limited ash storage elevation to ash dam top.

3.0.18

**Free board**

Height from flood storage level to ash dam top under limited ash storage elevation condition.

## 4 Basic Design Provisions

### 4.1 General Provisions

4.1.1 The environmental protection of ash storage yards shall meet the following requirements:

1 The ash storage yards shall be provided with safe and stable dam bodies that comply with relevant design standards to prevent ash, slag and ash water from flowing away.

2 The ash storage yards shall be equipped with reliable drainage systems, with drainage structures being located at a distance sufficient to clarify ash water and able to recycle the clarified ash water.

3 During the operation of ash storage yards, the limited length of dry bank shall be maintained to ensure the safety of dam bodies, while the ash surface of dry bank shall be wetted, when necessary, by diverting ash water thereto or sprinkling water to prevent dust pollution.

4 The ash storage yards shall be covered with soil and reclaimed promptly once they are filled up.

5 Where an impermeable layer is necessary at the bottom of ash storage yard as required by environmental impact report, it can be constructed of rolled clay or geomembrane. Vertical anti-seepage measures can be taken where geological conditions are permissible.

6 The pollution control criteria of ash storage yards shall comply with GB 18599.

4.1.2 Ash and slag damming shall meet the following requirements:

1 The dam bodies shall meet the requirements of design code in terms of stability.

2 The dam bodies shall be equipped with effective seepage drainage facilities to lower phreatic lines and accelerate solidification of ash and slag.

3 Ash discharging pipes shall be arranged reasonably in dam front to discharge ash evenly and deposit coarse ash and slag.

4 The ash storage yards shall be equipped with reliable drainage systems to discharge ash water and flood promptly and form a sufficient length of dry bank.

5 Perfect and efficient organizations shall be set up to ensure satisfactory construction quality and safe operation through professional management.

4.1.3 In the design of ash dams, types of dam and seepage discharge facilities shall be selected according to construction material, method and environmental protection requirements, and dam seepage & anti-sliding stability calculations and static and dynamic analysis be conducted for various options by taking into account factors such as limited ash storage elevation, length of dry bank, flood, earthquake and etc. so as to determine optimal cross section of dam body and limited length of dry bank.

4.1.4 The stability of downstream dam slopes shall be calculated with following operating conditions:

1 Normal operating conditions.

1) Steady seepage occurring with limited ash storage elevation and limited length of dry bank;

2) Steady or non-steady seepage occurring with limited ash storage elevation and limited length of dry bank in case of design flood.

2 Abnormal operating conditions.

1) Steady or non-steady seepage occurring with limited ash

storage elevation and limited length of dry bank in case of check flood;

- 2) Occurrence of earthquake with limited ash storage elevation and limited length of dry bank.

## 4.2 Design Criterion and Phases

4.2.1 The capacity of ash storage yards shall meet the following stipulations:

- 1 In planning phase, ash storage yard shall be able to hold ash and slag generated over a period of about 20 a operation of power plants as calculated based on its planned capacity, thus meeting the requirements for power plants establishment.

- 2 In design phase, designers shall determine the initial land acquisition for ash storage yard which shall be able to hold ash and slag generated over a period of about 10 a of operation as calculated based on the designed capacity and coal type of power plants for this phase.

- 3 In case of ash and slag damming, the capacity formed by primary dam shall be able to hold ash and slag generated over a period of at least three years as calculated based on the designed capacity and coal type of power plants for this phase. The capacity formed by each subdam added should be able to store ash and slag actually discharged thereto over a period of about 3 a.

4.2.2 The aggregate capacity of ash storage yard shall be calculated per Formula (4.2.2) as below:

$$V=V_{\text{ef}}+W=(G-U)T/(\rho \eta)+W \quad (4.2.2)$$

Where:

$V$ —aggregate capacity of ash storage yard,  $\text{m}^3$ ;

$V_{\text{ef}}$ —effective capacity of ash storage yard,  $\text{m}^3$ ;

$W$ —pondage of ash storage yard,  $\text{m}^3$ ;

$G$ —annual amount of ash and slag calculated based on design type of coal, kg/a;

$U$ —annual (average) amount of ash and slag actually reclaimed, kg/a;

$T$ —service life of ash storage yard, a;

$\rho$ —dry density of ash and slag, based on actual data measured during the operation of ash storage yard(1000 kg/m<sup>3</sup> if no actual data is available), kg/m<sup>3</sup>;

$\eta$ —effective capacity utilization factor of ash storage yard.

4.2.3 The design criterion of ash dams in valley ash storage yards shall be determined in accordance with following requirements based on aggregate capacity and terminal dam height as well as degree of hazard to neighboring and downstream areas after collapse.

1 Design criterion for ash and slag damming in valley ash yards shall comply with Table 4.2.3.

2 Where there are major industrial and mining enterprises or densely populated areas at the downstream, design criteria for ash dams may be raised by one class through demonstration.

3 When terminal dam height is different from aggregate capacity in class, the higher class shall prevail. If the difference is larger than one class, the class below the higher one shall be adopted.

4 The dam top of Class I ash dam shall have at least 1.5 m extra height; and those of Class II and III ash dams 1.0 m-1.5 m extra height.

5 The terminal dam height is generally determined according to the natural topography and geological conditions of ash storage yard. Where conditions are favorable, the terminal dam height may be determined based on ash storage required for 30 a design service life of fuel-fired power plants.

Table 4.2.3 Design criterion for ash and slag damming in valley ash yards

Design Class	Index for Classification		Recurrence Interval of Flood <sup>a</sup>		Free board m		Anti-sliding Safety Factor			
	Aggregate Capacity, $V \times 10^8 \text{ m}^3$	Terminal Dam Height, $H$ m	Design Condition	Check Condition	Design Condition	Check Condition	Downstream Slope	Upstream Slope	Abnormal Operating Condition	
I	$V > 1$	$H > 70$	100	500	1.5	0.7	1.30	1.10	1.15	1.00
II	$0.1 < V \leq 1$	$50 < H \leq 70$	50	200	1.0	0.5	1.25	1.05	1.15	1.00
III	$V \leq 0.1$	$30 < H \leq 50$	30	100	0.7	0.4	1.20	1.05	1.15	1.00

6 In case the terminal dam height is far over dam height designed for this phase, if the design class of ash dam is to be determined based on the design dam height and capacity for each construction phase, an overall planning shall be conducted from initial phase up to the terminal dam height, so as to enable the ash dam built in each phase to meet the subsequent higher security requirements.

4.2.4 The design criteria for ash embankments in beach ash yards shall be determined based on their capacity in accordance with the following requirements, and be in harmony with the local design criterion of levee projects.

1 The design criteria for ash embankments built with ash and slag in beach ash yards shall be compliant with Table 4.2.4.

2 The ash embankments or wave walls in beach ash yards shall have at least 1.0 m extra height.

3 For sea beach ash yards, the accumulated frequency of design wave height can be adopted according to the following:

- 1) 13% for determination of elevation of embankment top;
- 2) 13% for determination of stability of slope armor and bed armor;
- 3) 1% for determination of strength and stability of parapets and quadrels at embankment top.

4 The design of beach ash yards shall comply with the relevant stipulations in JTJ 213 and JTJ 298.

4.2.5 The design criterion of ash embankments in plain ash yards can be as specified in 4.2.4.

4.2.6 The design of ash and slag damming shall include overall planning, design of primary dam and design of subdam heightening, and shall meet the following requirements.

Table 4.2.4 Design criteria for ash embankments built with ash and slag in beach ash yards

Design Class	Aggregate Capacity $V \times 10^8 \text{ m}^3$	Recurrence Interval of Design High-water-level Outside Embankment <sup>a</sup>				Recurrence Interval of Stormy Waves Outside Embankment <sup>a</sup>				Recurrence Interval of Flood Inside Embankment <sup>a</sup>				Safety Height Added on Embankment (or Wave Wall) Top m				Anti-sliding Safety Factor			
		Outside Embankment		Outside Embankment		Outside Embankment		Outside Embankment		Inner Side of Embankment		Inner Side of Embankment		Downstream Slope		Downstream Slope		Upstream Slope			
		Design Condition	Check Condition	Design Condition	Check Condition	Design Condition	Check Condition	Design Condition	Check Condition	Design Condition	Check Condition	Design Condition	Check Condition	Normal Operating Condition	Abnormal Operating Condition	Normal Operating Condition	Abnormal Operating Condition	Normal Operating Condition	Abnormal Operating Condition		
II	$V > 0.1$	50	100	50	50	50	200	4.0	0.0	1.0	0.5	1.25	1.05	1.15	1.00						
III	$V \leq 0.1$	30	100	50	50	100	30	0.4	0.0	0.7	0.4	1.20	1.05	1.15	1.00						

1 In the overall planning of valley ash storage yard, if natural topography and geological conditions are favorable at plant site, the designers should determine the aggregate capacity and terminal dam height based on the ash storage required for 30 a design service life of fossil fuel power generating units, and plan the sequence, scale and land acquisition for each construction stage accordingly. The designers should determine the height of primary dam and way of by-stage heightening through technical and economical comparison; and arrange the seepage discharge system, drainage system, ash-water recycling system and other facilities reasonably. The safety of drainage piping in ash storage yards should meet the requirements with terminal elevation of ash storage.

2 During the design of primary dam, the designers should determine the type and height of primary dam and design the dam body and base in conjunction with the planning of subdam heightening.

3 The subdam heightening shall be designed by stages on basis of good understanding of the characteristics of ash and slag to be used for subdam base. If the subdam is heightened such that it is higher than the design height of the first-stage subdam, the design shall be rechecked before starting next heightening.

### 4.3 Basic Information

4.3.1 The survey and test involved with primary dam shall include, among others, topographic survey and surveys in respect of hydrometeorology, engineering geology and hydrogeology, construction material investigation and tests and investigation on construction conditions.

4.3.2 The designers shall be acquainted with the basic design

information of original dam body and its construction and operation when designing subdams, and should survey and test the ground base (the deposited ash and slag) of subdam to be constructed in this phase and the construction materials to be used, and investigate construction conditions accordingly.

4.3.3 The survey extent and the basic information provided in each stage of survey shall comply with survey-related specifications and codes.

## 5 Primary Dam

### 5.1 Axis of Primary Dam

5.1.1 The axis of valley ash yards shall be determined according to the topography and geological conditions of dam sites through technical and economical comparison by taking into account such factors as subdam heightening in the future, drainage system, construction conditions, and environmental impact.

5.1.2 The axis of cofferdam in beach or plain ash yards shall be determined through technical and economical comparison in terms of enclosed area and cofferdam height by taking into account such factors as service life of ash storage yard, topography, geology, water level and stormy waves of tide (flood), occupied land, subdam heightening in the future, construction conditions and environmental impact.

5.1.3 The axis of cofferdam shall be connected by curves at turning points, with the radius of circular curves for beach ash yards being not less than 30 m; and that for plain ash yards not less than 15 m.

### 5.2 Height of Primary Dam

5.2.1 The elevation of the top of primary dams in valley ash yards can be calculated by Formula (5.2.1-1) – Formula (5.2.1-3), whichever is larger:

$$E=e+h_1+\Delta_1 \quad (5.2.1-1)$$

$$E=e+h_2+\Delta_2 \quad (5.2.1-2)$$

$$E=e+\Delta_3 \quad (5.2.1-3)$$

Where:

- $E$ — elevation of dam top, m;
- $e$  — limited ash storage elevation of ash yard, that is, the elevation of volume in ash yard required to store the design amount of ash and slag of power plants (taking into account capacity utilization factor), m;
- $h_1$ — design depth of flood storage, that is, the depth occupied by design flood above the limited ash storage elevation after design flood control calculation, m;
- $h_2$ — check depth of flood storage, that is, the depth occupied by check flood above the limited ash storage elevation after check flood control calculation, m;
- $\Delta_1$ — design value of free board (selected from Table 4.2.3), m;
- $\Delta_2$ — check value of free board (selected from Table 4.2.3), m;
- $\Delta_3$ — dam extra height, m.

5.2.2 The height of primary dams in valley ash yards can be generally calculated and determined based on the service life of ash storage yard. Where the design flood volume of ash storage yard is very large and the topography is relatively special, the height should be determined through technical and economical comparison in the design phase.

5.2.3 The elevation of embankment top in beach ash yards shall be calculated respectively on the inner side and outer side of embankment, and then determined after coordination.

With ash storage conditions at inner side, the elevation of embankment top can be determined as specified in 5.2.1.

With flood protection conditions at outer side, the elevation of embankment top can be calculated by Formula (5.2.3) below:

$$E=HWL+R+\Delta \quad (5.2.3)$$

Where:

$E$  —elevation of embankment top, m;

$HWL$  —design (check) high water level, m;

$R$  —height of wave runup at design (check) high water level, m;

$\Delta$  —design (check) value of safety height added on embankment top (selected from Table 4.2.4), m.

5.2.4 The elevation of embankment top in plain ash yards can be determined by Formula (5.2.1-3).

### 5.3 Type Selection of Dam

5.3.1 The type of dam shall be selected by taking into account the following factors.

1 Category, nature, reserves, distribution, burial depth, the exploitation and transportation conditions of local materials available for constructing the dam;

2 Requirements for reducing the height of phreatic line and accelerating the solidification of ash and slag by subdam heightening in the future;

3 Geological condition, seismic fortification intensity and other conditions;

4 Downstream environmental conditions and environmental protection requirements;

5 Construction progress, construction site, construction machineries, and technical level of construction;

6 Total work quantity, construction period, and total construction cost.

5.3.2 The types of primary dam can be selected according to the difference of permeability between construction material of dam and ash and slag as follows.

1 For highly permeable dams, the permeability coefficient of construction material used for dam body shall be 50 times more than that of ash and slag or more than  $1 \times 10^{-2}$  cm/s.

2 For with lowly permeable dams, the permeability coefficient of construction material used for dam body shall be similar to that of ash and slag.

3 For impermeable dams, the permeability coefficient of construction material used for dam body shall be 50 times less than that of ash and slag or less than  $1 \times 10^{-5}$  cm/s.

4 For impermeable dam equipped with seepage drainage facilities in the dam front, the dam body shall be built with impervious earth or artificial materials, with effective seepage drainage media provided in the dam front.

5.3.3 The following types can be selected for primary dam according to different structures of cross section of dam body.

1 For homogeneous dams, the dam body can be constructed into permeable dam, impervious dam, or impervious dam provided with seepage drainage media in dam front by using homogeneous materials.

2 For zoned dams, the dam body can be constructed by zones into permeable dam, impermeable dam, or impermeable dam provided with seepage drainage media in dam front by using earth-rock materials or artificial materials with different permeability.

5.3.4 Where local sand and stone is sufficient, permeable dam with high permeability can be adopted. However, if the seepage water has negative effect on downstream environmental protection, effective protective measures shall be taken.

5.3.5 Impermeable dam is not suitable for newly-built primary dams. Where sufficient cohesive soil is available nearby, or

downstream environmental protection necessitates an impermeable dam, an impermeable dam with seepage drainage media in dam front shall be adopted.

## 5.4 Construction Material

5.4.1 The construction material shall preferably:

1 Be sourced from local materials, especially those within ash yards, thus occupying less or no farm land outside ash yards.

2 Be economically rational by taking into account construction conditions such as mining, transportation and compaction, and even seasons.

3 Meet the requirements for primary dams, later subdam heightening, seepage drainage and environmental protections after overall technical demonstration.

5.4.2 The construction materials must be selected reasonably from within ash yards and neighboring areas after necessary investigation and test in respect of their types, nature, reserves, distribution, burial depth, mining, transportation and construction conditions.

5.4.3 The construction materials of dams shall comply with following stipulations:

1 For rockfill dams or masonry dams, the rock material used for them should be greater than 30 MPa in compressive strength, greater than 0.75 in weathering coefficient, and greater than 0.80 in softening coefficient.

2 For ballast dams, the material used for Class I dam body shall have a weathering coefficient of more than 0.40 and a softening coefficient of more than 0.80; while those used for Class II and III dam bodies may have a weathering coefficient of less 0.40 and a softening coefficient of more than 0.65.

3 For earth-rock dams, the materials to be used may include earth and rocks that have relatively high strength and stability after compaction, and cohesive soil, sandy soil, gravel soil and weathered materials which contains no more than 5% of organic matter. When weathered soft rock, collapsible loess, expansive soil and the like are used as dam materials, appropriate engineering measures shall be taken. Boggy soil and soil containing incompletely decomposed organic matter are not suitable.

5.4.4 The rock materials used for seepage drainage shall be resistant to weathering and strong enough when immersed in water. In addition, their compressive strength shall be more than 40 MPa, weathering coefficient more than 0.80, softening coefficient more than 0.85, the grain size gradation and controlled diameter shall meet design requirements.

5.4.5 The inverted filter media shall comply with the following stipulations:

1 When sand and stone are used as the inverted filter media, the grain size gradation of each layer of filter media shall meet design requirements, wherein grains smaller than 0.1 mm in diameter shall be no more than 5%, and shall be compact, hard and highly resistant to water and weathering. Weathered materials shall not be used as inverted filter media.

2 When geotextile is used as inverted filter media, it shall meet the design requirements in terms of physical performance, mechanical performance, hydraulic performance, durability, and comply with GB 50290.

5.4.6 The impermeable materials shall meet the following stipulations:

1 Cohesive soil having an osmotic coefficient less than  $1 \times 10^{-5}$  cm/s and satisfactory plasticity and seepage stability and the same containing gravel can both be used as impermeable material.

2 When collapsible loess or loess-like soil is used as impermeable material, it shall be appropriately filled with water and compacted densely, and be combined with suitable inverted filter media. When expansive soil is used as impermeable material, it shall be covered heavily.

3 The following materials are not suitable for impermeable material: alluvial clay with a plasticity index of more than 20 and liquid limit of more than 40%, clay that significantly expands and softens when immersed in water, and those that are difficult to excavate and compact, such as dry and hard clay, dispersive soil and frozen earth. If these soils must be employed, special demonstration shall be made, and relevant measures be taken.

4 Where local impermeable soil is not sufficient, artificial impermeable material such as geomembrane can be employed. The geomembrane shall have an osmotic coefficient of less than  $1 \times 10^{-11}$  cm/s, shall meet the design requirements in terms of physical performance, mechanical performance, hydraulic performance and durability, and shall comply with GB 50290.

5.4.7 The protective coverings shall meet the following stipulations:

1 When rock materials are used as protective coverings, they should be compact and highly resistant to weathering with a compressive strength greater than 30 MPa, a weathering coefficient greater than 0.80, and a softening coefficient greater than 0.80.

2 When lawn is used as protective coverings, it shall be liable to take root and spread, and be drought-tolerant.

3 When concrete blocks are used as protective coverings, they shall meet the requirements for strength and anti-freezing.

## 5.5 Filling of Dam Bodies

5.5.1 The dam body shall be filled with earth (or rock) in specified

compactness and uniformity and be compacted evenly.

5.5.2 The design filling criterion for dam bodies shall be determined by comprehensively analyzing the factors such as class of ash dam, construction materials, compacting method, seismic fortification intensity and cost effectiveness through compaction tests.

5.5.3 The filling criterion for gravelly and cohesive soil shall take the dry density of design filling as design control index. The dry density of design filling shall be determined by multiplying maximum dry density with compactness. The compactness for Class I and II ash dams shall not be lower than 0.96; that for Class III ash dam not lower than 0.95. Where the seismic fortification intensity is higher than 7 degree, the compactness shall be increased appropriately. The maximum dry density and optimal water content shall be determined through compaction tests.

5.5.4 The designers shall determine the maximum dry density of gravelly soil through large-scale compacting test and the dry density of design filling as per 5.5.3 respectively. For gravelly soil containing less than 30% of crushed stones, the designer shall determine the dry density of design filling by performing compaction test with fines and modifying the test results.

5.5.5 The filling criterion for sandy gravel and sand shall take relative compactness as design control index. The relative compactness of sandy gravel shall not be less than 0.75, and that of sand not less than 0.70. Where the seismic fortification intensity is higher than 7 degree, the relative compactness of sandy gravel below phreatic line shall not be less than 0.75.

5.5.6 The filling criterion for rockfill material should take porosity as design control index, which should not be greater than 30%.

5.5.7 As being related with the nature and crushability of parent

rock, the compactness of ballast material shall be determined through rolling test controlled by dry density of design filling. Generally, its compactness shall not be less than 0.96.

5.5.8 For soil with special nature, the filling criterion shall be determined through special tests.

5.5.9 When dam body being built on soft ground, reasonable engineering measures shall be determined through calculation, analysis and technical and economic demonstration. During construction, filling speed shall be controlled by checking the soil displacement and pore water pressure.

5.5.10 When earth-rock material is used for primary dam, rolling method is preferred. When sand, sandy clay or ash and slag are used for primary dam and water sources are available, hydraulic filling-siltation method can be employed.

## 5.6 Construction of Dam Top

5.6.1 The minimum width of dam top should not be less than 4.0 m taking into account the ash piping laid on top, roads for operation or maintenance and space required for mechanized construction.

5.6.2 The dam top shall be paved with covering materials, such as compacted sandy gravel, ballast or mixture of soil and gravel. For beach ash yards whose dam top may be washed over by flood, grouted stone blocks or concrete containing the same should be used as covering material. When dam top is to serve as traffic road, the covering material shall be determined according to applicable road standards.

5.6.3 When ash piping is disposed on dam top, it should be laid as close to the upstream side as possible.

5.6.4 The top surface of dam should have drainage slopes inclining

towards both sides or either side with a gradient in the range of 2%–3%.

5.6.5 For beach ash yards whose embankment tops have wake walls, movement joints shall be provided in the walls.

5.6.6 When it is necessary to provide lighting facilities on dam top for the operation of ash yard, the lighting facilities shall meet applicable stipulations.

### 5.7 Structure of Dam Slope

5.7.1 The gradient of dam slope shall be determined through stability calculation taking into account factors including height of dam, construction material of dam body, conditions of dam base, location of phreatic line and seismic fortification intensity.

5.7.2 At the locations where the gradient of dam body changes, berms shall be provided, and should have a width of no less than 1.5 m. Where the downstream slope has a constant gradient and the height of dam is less than 10 m, no berm is required; where the height of dam is more than 10 m but less than 20 m, a berm can be provided in the middle of dam; where the height of dam is more than 20 m, berms can be provided at intervals of 10 m–20 m upwards with the first one being provided at the height of 10 m. There can be no berms for upstream slope. If a beach ash yard is provided with a platform for dissipating waves, the top of such platform may serve as a berm.

5.7.3 Where the downstream slope of dam body is subject to damages such as rainwater scouring, aeolian erosion, frost heave and dry crack, it shall be provided with a protective slope. If the downstream slope is built of block-stone, cobble or crushed stones, the protective slope can be omitted.

5.7.4 Where the upstream slope is built of stones, the protective slope is not required; where the upstream slope is built of earth, the

protective slope shall be provided in following cases:

- 1 Where the dam surface is built of materials liable to be washed away, such as silty and sandy soils;
- 2 Areas in ash storage yard where water is frequently impounded and it is difficult to maintain the length of dry bank;
- 3 Area within 1 m above the lowest drain of ash yard;
- 4 Areas at both sides of ash discharging pipes on dam slope.

5.7.5 The protective slope can be built of riprap, dry stone masonry, stone masonry, cobble-stone or crushed stone, lawn, concrete protective cover, earth-filled concrete grid, earth-filled geogrid and bagged concrete in accordance with the principle of obtaining raw material from local sources as practical as possible.

5.7.6 For beach ash yard, the structure and construction material of the protective slope at the outer side of ash embankment shall be determined through calculation in accordance with the requirements for protection against tides and waves. The calculation results shall be checked by cross section model testing when necessary.

5.7.7 For valley ash yard, the slope face of downstream dam shall be provided with treads leading to dam top.

5.7.8 Where runoff may flow down along the downstream slope of dam body, vertical and longitudinal drainage ditches shall be provided, with the vertical ones being arranged at an interval of 50 m–100 m along the whole length of dam, longitudinal ones arranged at the inner side of berms. In addition, drainage ditches built of stone masonry or concrete masonry shall be provided at the junction of dam body with bank slope.

5.7.9 Foundations shall be provided not only at protective slopes built of riprap, but also at berms, dam foot and the end of protective slope.

## 5.8 Seepage Drainage Facilities of Dam Bodies

5.8.1 The dam body shall be provided with seepage drainage facilities to reduce the height of phreatic line and protect against pervasion, so as to maintain the steadiness of dam slope and dam body. The seepage drainage facilities must meet the following requirements:

- 1 The seepage drainage facilities shall be able to discharge all seeped water to the downstream;
- 2 The seepage drainage facilities shall be of reverse osmosis design.

5.8.2 The seepage drainage facilities may comprise both upstream and downstream seepage drainage systems of the following types:

- 1 Upstream seepage drainage system: horizontal longitudinal pipes (ditches), latitudinal pipes (ditches), vertical wells, seepage drainage layers in dam slope, seepage drainage layers in bank slope, seepage drainage mattress, as well as any combinations thereof;
- 2 Downstream seepage drainage system: drainage prism, drainage along dam slope, drainage mattress extending into dam body, as well as any combinations thereof.

5.8.3 The type of seepage drainage system shall be selected taking into account the following factors:

- 1 Type of dam, natures of filling earth or ash and slag;
- 2 Engineering geological and hydrogeological conditions of dam base;
- 3 Effects of water level and silt deposited at the downstream of dam body;
- 4 Climatic conditions in area where to build the dam;
- 5 Supply of seepage facilities and materials;

6 Construction conditions;

7 Resultant cost.

5.8.4 The design of seepage drainage system at the downstream of dam body shall meet the following requirements:

1 The height of drainage prism shall ensure that the distance between the phreatic line of dam body and downstream slope face is larger than local freezing depth but should not be less than  $1/4$  of the maximum height of primary dam, while the width of prism top should not be less than 1.0 m. There shall be no sharp angles at the upstream toe of the prism where drainage ditches shall be provided;

2 The top of drains along dam slope shall be higher than the overflow point of phreatic line of dam body, and the extra height should be larger than the local freezing depth and not be less than 1.5 m; while the thickness of drains along dam slope shall not be less than the freezing depth, and drainage ditches or systems shall be provided at slope toe;

3 Where horizontal drains in the dam are of mattress type, the thickness of mattress and its depth extending into the dam body shall be calculated according to the seepage. Where horizontal drains are net-like, the thickness and width of longitudinal drainage strips (parallel to the axis of dam) shall be calculated according to seepage volume, while the latitudinal drainage strips shall be not less than 0.5 m in width with a spacing of 30 m–100 m and a gradient not greater than 1%. If seepage volume is relatively large, drainage pipes can be employed;

4 The limited length of horizontal drains extending into the dam body is follows, for homogeneous dams built of cohesive soil,  $1/2$  of the width of dam bottom; for homogeneous dams built of sandy soil (including ash and slag),  $1/3$  of the width of dam bottom;

for zoned earth dams with impermeable bodies, the drains should be connected with inverted filter layer at the downstream of impermeable bodies.

5.8.5 In the design of seepage drainage facilities at the upstream of dam body, the designers shall determine their reasonable types and locations through seepage calculations and tests according to the permeability of primary dam and heights added by subsequent subdams, and the following requirements shall be met:

1 In case of horizontal seepage drainage piping, it shall be laid in dam front parallel to dam axis, and should employ open-ended steel pipes, reinforced concrete pipes or plastic pipes with rock material and inverted filter layers being laid outside;

2 Where horizontal seepage pipes cannot meet the requirements for seepage drainage, net-like seepage drainage pipes (ditches) or their combination with vertical seepage drainage wells are preferred;

3 Where it is required to increase seepage drainage capacity, seepage drainage layers can be provided at the upstream slope of dam and at both sides of the bank slope, and shall be connected to with the network of seepage drainage pipes for combined effect;

4 The water from the seepage drainage facilities at the upstream of dam body shall discharged through the drainage pipes to the downstream. If recovery is required, the water shall be led to ash water recovery system through drainage pipes. The drainage pipes can be equipped with control valves which can be opened before heightening the ash dams so as to prevent the seepage drainage facilities from being blocked.

## 5.9 Impermeable Media

5.9.1 Where impermeable bodies are required for the primary dam,

they can be built of earth or artificial materials according to materials available locally.

5.9.2 The structure of impermeable bodies built of earth shall be determined according to the following factors:

- 1 The reserve and the exploitation conditions of the impermeable earth available locally;
- 2 The permissible seepage gradient, plasticity and crack resisting performance of impermeable earth;
- 3 The local seismic fortification intensity;
- 4 The nature and treatment method of ground base beneath impermeable bodies.

5.9.3 For impermeable bodies built of earth, the cross section shall be thickened gradually from top to bottom, and the horizontal width of their top should meet the requirements by construction machinery, their bottom thickness for oblique core walls and for core walls should not be less than  $1/5$  and  $1/4$  of water head respectively. The elevation of the top of impermeable body shall not be less than that of the flood level above limited ash storage elevation as well as that of the phreatic line when subdams are heightened.

5.9.4 The impermeable bodies built of earth shall be provided with protections at the top and upstream slope. These protections which can be made up of permeable materials are used to prevent impermeable earth from freezing and cracking, as well as direct seepage water to the seepage drainage facilities in the dam front. The thickness of the protections shall not be less than the freezing depth or drying depth in local area, while the gradient shall meet the requirements for stability.

5.9.5 Where impermeable geomembrane is used as artificial impermeable body, the slope face of dam shall be leveled and

compacted. The surface of geomembrane shall be covered with a protective layer of sandy gravel and a protective paving outside. The junctions of geomembrane shall be leak-free. The application of geomembrane shall meet the relevant technical requirements specified in GB 50290.

### 5.10 Inverted Filter

5.10.1 Inverted filters shall be provided at the interfaces between the upstream/downstream seepage drainage facilities and the dam body or the ash and slag, between the impermeable bodies built of earth and the dam body or the permeable ground base, between different types of earth, and between the dam body and the ground base earth if the requirements for interlayer impermeable coefficients cannot be met.

5.10.2 For inverted filters that are made up of sandy gravel, the following design requirements shall be met:

1 The particles of each inverted filter layer shall not pass through adjacent layer made up of larger-sized particles. In addition, the inverted filter is required to meet the criterion for earth preservation as follow:

$$D_{15}/d_{85} \leq 4 \sim 5 \quad (5.10.2-1)$$

Where:

$D_{15}$ —Particle size of earth that constitutes protective layer (the earth whose particle size being less than  $D_{15}$  accounts for 15% of total mass), mm;

$d_{85}$ —Particle size of earth that constitutes protected layer (the earth whose particle size being less than  $d_{85}$  accounts for 85% of total mass; for  $d_{85}$ , the smaller value should be taken in the above formula for downward seepage, and the

larger value for upward seepage), mm.

2 The inverted filters shall have good permeability and meet the criterion for permeability as follows:

$$D_{15}/d_{15} \geq 5 \quad (5.10.2-2)$$

Where:

$D_{15}$ —Particle size of earth that constitutes protective layer (the earth whose particle size being less than  $D_{15}$  accounts for 15% of total mass), mm;

$d_{15}$ —Particle size of earth that constitutes protected layer (the earth whose particle size being less than  $D_{15}$  accounts for 15% of total mass), mm.

3 The particles in each inverted filter layer shall not move relatively therein, and shall have an uneven coefficient in the range of 5-8.

5.10.3 For inverted filters that are made up of sandy gravel, the thickness of each inverted filter layer shall be determined comprehensively in accordance with grain size distribution of material, source, purposes of application, and construction methods. For manual construction, the minimum thickness of horizontal inverted filter can be 0.30 m, and that of vertical or oblique inverted filter 0.50 m; for mechanical construction, the minimum thickness shall be determined according to the actual construction method.

5.10.4 During filling process, the inverted filter made up of sandy gravel should be raised along with the dam body, and shall be free of apparent separation and crashing of particles.

5.10.5 For inverted filter that is made up of geotextile, the following design criteria shall be met:

1 Earth preservation:

$$O_{95} \leq d_{85} \quad (5.10.5-1)$$

2 Permeability:

$$O_{95} \geq d_{15} \quad (5.10.5-2)$$

$$K_g \geq 25K_s \quad (5.10.5-3)$$

Where:

$O_{95}$ —Equivalent pore diameter of geotextile (the pore diameter that retains 95% of earth on geotextile after sieving), mm;

$d_{85}$ —Particle size of earth that constitutes protected layer (the earth whose particle size being less than  $d_{85}$  accounts for 85% of total mass), mm;

$d_{15}$ —Particle size of earth that constitutes protected layer (the earth whose particle size being less than  $d_{15}$  accounts for 15% of total mass), mm;

$K_g$ —Permeability coefficient of geotextile, cm/s;

$K_s$ —Permeability coefficient of protected earth, cm/s.

3 Anti-blocking: when a blocking test is conducted with earth sample and geotextile, the resultant gradient ratio shall not be greater than 3.

### 5.11 Junctions of Dam Body with Ground Base, Bank Slope and Burial Pipes

5.11.1 The junctions of dam body with ground base, bank slope and burial pipes shall be properly treated, so as to prevent against damage resulting from concentration of seepage water, to prevent from forming soft layers that can affect the stability of dam body, as well as to prevent against uneven settlements resulting from improper junctions.

5.11.2 The junctions of dam body with soil base and bank slope shall meet the following requirements:

1 The soil base shall be thoroughly removed of grasses, tree

roots and surface soil containing organic matter, cyclopean, rubbish, caves, or other wastes within the whole cross section of dam. Then the surface soil over the base shall be compacted. The bank slope shall be excavated evenly and flatly without any stair-shaped, adverse, or toothed slopes. The bank slope that junctions with impermeable bodies built of earth should have a gradient less than 1:1.5;

2 The impermeable bodies shall be located on soil bases that are relatively impermeable, or on dam foundations that have undergone seepage-proof treatment.

5.11.3 The junctions of dam body with rock base and rock bank slope shall meet the following requirements:

1 The rock base and rock bank slope shall be removed of loose and prominent stones, and soil accumulated in recesses within the whole cross section of dam. The bank slope that junctions with impermeable bodies built of earth should have a gradient less than 1:0.5;

2 The junctions of impermeable bodies with rock base and rock bank slope can be joined soundly by excavating tooth-shaped slots and blocking the joints, fissures and faults with concrete or mortar.

5.11.4 The junctions between dam bodies and drainage pipes shall meet the following stipulations:

1 For concrete drainage pipes, flexible and leakage-proof connections shall be employed with concrete sealing rings being provided around the pipes;

2 For steel pipes, anticorrosion measures shall be taken, with steel sealing rings being provided around the pipes;

3 The earth around the pipes shall be carefully compacted in layers to prevent seepage from concentrating at their interfaces, or

prevent cracks from occurring on the dam body due to uneven settlement;

4 Where drainage pipes pass through rockfills, they shall be filled with cushion layers of sandy gravel or crushed stone in layers, with no block stones contacting the pipe wall directly.

## 5.12 Treatment of Dam Foundation

5.12.1 The treatment of dam foundations shall meet the requirements in terms of stable seepage, seepage volume control, static and dynamic stability, uneven settlement so as to ensure safe operation of dam body and protection of downstream environment.

5.12.2 When the dam foundation happens to be one of the following undesirable bases, it shall be investigated and treated prudently:

- 1 Silt layer, soft clay layer or other soft soil layers with low strength and high compressibility;
- 2 Soil layers that may liquefy in case of earthquake;
- 3 Collapsible loess;
- 4 Carst;
- 5 Fissures and fractured zones;
- 6 Wells, holes, and mouths of springs within mining regions.

5.12.3 The treatment measures of dam foundations shall be determined according to the type of ground base soil in conjunction with construction conditions through technical and economical comparison. Tests shall be conducted when necessary to select economical and reasonable treatment methods.

5.12.4 For soft-soil ground base, if the soft soil layer is not very thick and is located relatively shallowly beneath the surface of ground, it can be excavated and refilled with other materials. If the soft soil

layer is relatively thick, applicable treatment methods can be used depending upon actual conditions, such as tamping, pre-compacting, excavating sand pits, inserting drainage boards, riprapping to squeeze silt, exploding to expel silt and vibroflotation.

5.12.5 For soil layers that may liquefy, applicable methods can be used to treat their bases depending upon actual conditions, such as excavation, intensified drainage, vibrating compaction, forced ramming, vibroflotation, and sand/gravel piles.

5.12.6 Collapsible loess can be used for dam foundations of low dams in hydraulic ash yards. However, the effect of settlement, collapse, and lixiviation of collapsible loess on earth-rock dams shall be demonstrated, and the collapsible loess shall be treated properly. When collapsible loess is used as construction material of dam foundation, it should be treated with appropriate methods, such as excavation, digging-and-compaction, and forced ramming so as to eliminate its collapsibility. It can also be treated with presoaking method after relevant demonstration.

5.12.7 Where the ground base is broken and cracked rock or hillside soil, the necessity of treatment shall be determined depending upon the effect of seepage, soil piping, and dissolution on the dam foundation and dam body. When treatment is necessary, appropriate construction methods can be used, such as grouting with concrete, and laying geomembrane.

5.12.8 Where impermeable ash dams are located on ground bases that is made up of permeable sand/cobble, and the seepage volume needs to be controlled as required by the environmental protection rules, some seepage interception facilities can be used down to the depth of relative impermeable layers, such as cut-off walls built of cohesive soil or concrete, and grouted curtains. If dam body is

equipped with impermeable bodies, seepage interception facilities shall be closely joined with impermeable bodies. For impermeable homogeneous dams, the seepage interception facilities can be disposed at the locations where the distances away from the upstream toes of dams are  $1/3-1/2$  of the widths of dam bases. For permeable dams, such facilities can be disposed outside the downstream toes of dams.

## 6 Subdam

### 6.1 Subdam Heightening

6.1.1 The subdams shall be heightened according to the overall planning of ash yard. The grading of subdams and the height of each subdam shall be determined comprehensively by taking into account multiple factors, such as topography of ash yard, period of ash storage, construction material of subdam, construction conditions, solidification of ash and slag, stability of dam body, experience in operation of power plants, and construction cost.

6.1.2 The subdam should be heightened once every 3 a period of ash storage.

6.1.3 The height of each subdam shall meet the requirements for period of ash storage and flood protection, and be determined through technical and economical comparisons.

6.1.4 The axis of subdam should be horizontally arranged next to the upstream side of the top of preceding dam. When dam body cannot meet the requirements for stability, the axis of subdam can be moved upward moderately.

6.1.5 The effect of flood seasons and freezing seasons should be taken into account in deciding the construction method for heightening subdams. Generally, rolling method is suitable for subdam heightening. When heightening subdams with ash and slag, hydraulic filling-siltation method can be used.

6.1.6 When heightening subdams, the design shall be based on analyzing the observation data on phreatic lines of preceding dam

bodies, and exploring and testing the preceding dam bodies and the ground base formed by deposited ash and slag.

6.1.7 When the heightened subdams exceed the original planned height, the safety of drainage structures that have been built shall be checked, and those that cannot meet the requirements for subdam heightening shall be reinforced or reconstructed.

## 6.2 Material and Structure of Subdams

6.2.1 Local earth-rock material or deposited ash and slag can be used for subdams, and shall meet the following requirements:

1 When earth-rock material is employed, it is advisable to build homogeneous subdams or zoned subdams with oblique core walls using materials with a permeability coefficient lower than that of deposited ash and slag, so as to prevent positively seepage water from escaping at the downstream slope of subdam;

2 When earth-rock material with permeability greater than that of ash and slag is employed, geosynthetic materials should be provided on the upstream face;

3 When ash and slag is used to fill the subdams, the upstream slopes shall be provided with impermeable layers, and the downstream slopes inverted filters. The surfaces of both upstream and downstream slopes shall be provided with protective covers.

6.2.2 The gradient of subdam shall be determined according to the height of subdam, construction material, solidification of ash and slag constituting dam foundation, location of phreatic line and seismic fortification intensity by taking into account the stability of individual subdams in question and the entire ash dam. The upstream slope of individual subdam should not be sharper than 1:1.5. While the downstream slope not sharper than 1:2.0. The downstream slopes of

all subdams above the primary dam should not be sharper than 1:3.5 on average.

6.2.3 The toe of downstream slope of subdam shall be joined closely with the slope of preceding dam, with a joining thickness not less than 2 m.

6.2.4 The width of subdam top shall be determined as required by ash pipeline laying, access passage for operation and maintenance, mechanized construction, etc. In case of no special requirement, such width is generally 4.0 m.

6.2.5 The subdam top shall be paved with covering materials, such as compacted sandy gravel, crushed stone, a single layer of dry block-stone masonry, or mixture of soil and gravel. Where the subdam top is used as access passage for operation and maintenance, it is generally paved with mixture of soil and gravel.

6.2.6 Where the subdam top is equipped with ash piping, ash pipes should be laid as close to upstream side as possible.

6.2.7 The top face of subdams shall be provided with drainage slopes inclining towards the ash yard, and should have a gradient in the range of 2%-3%.

6.2.8 The junctions between subdams and bank slopes shall be treated properly. The bank slopes shall have their ground bases cleaned thoroughly, and be excavated flatly and smoothly. The impermeable bodies of subdams shall sit on relatively impermeable ground bases, embed into tooth-shaped slots excavated down below severely weathered rock formation in the bank slopes, or extend towards upstream moderately along the bank slope so as to increase seepage paths.

6.2.9 The junctions between the downstream slopes of subdams and the bank slopes as well as the toes of downstream slopes shall be

equipped with drainage ditches which can be built of stone masonry.

### 6.3 Seepage Drainage Facilities for Subdam

6.3.1 The necessity of providing seepage drainage facilities for subdam shall be determined through seepage calculation or tests in combination with the type of preceding dam and the actually measured phreatic line on preceding dam body.

6.3.2 If the preceding dam has low permeability and high actually measured phreatic line, the subdam shall be equipped with seepage drainage facilities at upstream. Horizontal pipes, net-structured pipes, radial pipes, French drains, and any combinations thereof can be selected for seepage drainage facilities, their actual types and locations shall be reasonably determined through seepage calculation or tests.

6.3.3 Where there tends to be flood from time to time in the front of subdams, or it is hard to maintain dry bank for a long-term, seepage drainage facilities shall be provided at the bottom of subdam. With their types and locations being determined through seepage calculation or tests rationally. Generally, the suitable seepage drainage facility is horizontal piping, with the seepage water being directed to the downstream of subdam by latitudinal pipes.

6.3.4 The horizontal seepage drainage pipes shall be laid parallel to the axis of dam. The suitable seepage drainage pipes are plastic pipes or open-ended steel pipes with cobble/crushed stone and geotextile filter laid outside, or permeable hoses with filter layers. The diameters and seepage capacities of such pipes and hoses shall be determined through seepage calculation or tests.

### 6.4 Hydraulic Filling Damming of Ash and Slag

6.4.1 This technique applies to the following cases:

1 Subdam heightening. For primary dams, such technique must be qualified and subjected to feasibility demonstration prior to application.

2 There must be sufficient water, generally clarified water in ash yard.

3 There must be sufficient mechanical power sources, generally the power supplies exclusively used by ash yard.

4 This technique applies when the daily outdoor mean temperature is not lower than 5°C.

5 This technique is applicable to deposited ash and slag with following features:

- 1) Content of particles with a diameter larger than 0.5 mm being lower than 15%;
- 2) Content of particles with a diameters ranging 0.5 mm-0.005mm being higher than 70%;
- 3) Content of particles with a diameter less than 0.005 mm being lower than 15%;
- 4) Permeability coefficient K being not less than  $1 \times 10^{-4}$  cm/s;
- 5) Content of organic matter being less than 5%.

6 This technique applies to areas with seismic fortification intensity up to 7 degree. For areas with seismic fortification intensity higher than 7 degree, dedicated demonstrations shall be made to determine the possibility to apply such technique.

7 When constructing subdams on soft base of ash and slag in the water area of ash yard using this technique, dedicated demonstrations on dehydration and solidification shall be made.

6.4.2 Sampling and testing of ash and slag shall meet the following requirements:

1 When deposited ash in the dry banks of ash yards is used as ash and slag for filling-siltation damming, representative samples shall be taken for testing.

2 Tests on materials constituting ash-slag dams shall be conducted in accordance with the relative stipulations in SL 237.

3 The geotechnical tests on ash and slag shall cover following items:

- 1) Relative density (specific gravity), dry density and moisture content;
- 2) Grain size analysis;
- 3) Permeability test;
- 4) Compaction test;
- 5) Relative compactness test;
- 6) Shearing test (including dynamic and static triaxial tests for areas with seismic fortification intensity of 7 degree and above);
- 7) Indoor simulation tests on hydraulic filling of ash and slag, to measure indexes used to calculate the stability of dam bodies.

6.4.3 Hydraulic filling damming of ash and slag shall be up to the following criteria:

1 The compactness of filled ash and slag:  $\geq 0.96$  for Class I and Class II ash dam;  $\geq 0.95$  for Class III ash dam.

2 The relative density of ash and slag shall not be less than 0.7, and not be less than 0.75 for ash and slag below phreatic lines in seismic zones.

6.4.4 The structures of dam bodies shall meet the following requirements:

1 The dam slopes that are hydraulically filled with ash and slag

shall meet the requirements for stability of dam body. The upstream slopes should not be sharper than 1:2.0, the downstream slopes not be sharper than 1:2.5;

2 The upstream slopes of ash-slag dam bodies shall be paved with reliable impermeable layers generally made of geomembrane and joined with abutments solidly;

3 The downstream slopes of ash-slag dam bodies shall be paved with reliable inverted filters generally made of geotextile;

4 The slope face of ash-slag dam bodies can be covered for protection by such materials as crushed stone, dry stone masonry, stone masonry and concrete slabs, depending upon the construction materials available locally;

5 The dam tops shall be paved with reliable covering materials;

6 The seepage drainage facilities of dam bodies shall meet the requirements for reducing the height of phreatic line during the operation of ash yard and dewatering and solidifying the ash and slag hydraulically filled during the construction of ash yard;

7 Tooth-shaped slots should be provided for joining the dam bodies and bank slopes, and their depths and bottom widths should not be less than 1.0 m, gradient not be less than 1:1.0.

6.4.5 The requirements on construction processes by design of filling-siltation damming of ash and slag are as follows:

1 The construction process in filling-siltation damming of ash and slag must include slurry preparation, hydraulically filling, stirring, vibro-densification, dewatering, and solidification.

2 The specific requirements are as follows:

- 1) The pits to fetch ash should be more than 40 m away from the toe of dam body being constructed, and be no more than 5 m in depth;

- 2) The ratio of ash slurry to ash water is generally ranging 1:3-1:4;
- 3) Where ash slurry is conveyed from a long distance, relay pumps can be used in the middle;
- 4) Each plot hydraulically filled in layers shall have a width commensurate to that of dam face, its length along the axis of dam should not be greater than 50 m;
- 5) The ridges used for enclosing the filled plots should be built by manually piling up ash and slag and compacting in layers. Generally, each layer of ash, 0.3 m thick, shall be compacted on both sides into trapezoid shapes with the bottom width of ridges being more than 1.0 m; the heights greater than 0.6 m. The adjacent upper and lower layers of ridge used as intermediate partitions should be staggered by more than 2.0 m;
- 6) The inside and outside slopes need to be filled with excessive ash and slag of not less than 0.3 m, should be cut into the final shapes at one attempt;
- 7) The thickness of each shaped layer of filled ash and slag should not be greater than 0.4 m;
- 8) For filling each layer of plots, there should be at least two slurry outlets which should be arranged diagonally;
- 9) When each plot is filled up, there should be two outlets provided for discharging the surface water;
- 10) After the surface water is discharged, the filled plots must be stirred with the density of stirring points being not be greater than 1.0 m;
- 11) When stirring with vibrating rods, their moving speed should not be greater than 1 m/min, the row spacing not

be greater than 0.5 m;

- 12) Having been manually stirred and trampled, the filled ash slurry shall be compacted twice longitudinally and latitudinally respectively by using plate vibroflots with a moving speed not greater than 2 m/min;
- 13) When a plot at one side of a ridge has been filled up, and the plot at the other side of such ridge needs to be filled, this ridge shall be manually stirred, trampled and compacted at least twice.

3 The water intake pumps and pumps used for conveying ash slurry should be powered by the exclusive power supply for ash yard.

4 Prior to each formal filling, on-site filling test must be carried out to determine the quality parameters that meet design requirement and instructions for construction process. The parameters shall include, among others, water-ash ratio of ash slurry, dimension of plots, duration of hydraulic filling, duration of discharging surface water filled in plots, duration of stirring and trampling lower layer, duration of compacting upper layer, compactness and relative compactness.

5 During construction period, the settlement at the center of dam body shall meet the following requirements: the maximum daily settlement is 15 mm; accumulated settlement for two consecutive days shall be less than 20 mm.

6 The permissible hydraulic filling speed of dam body shall meet the following stipulations:

- 1) The maximum increase in height every three days is 0.4 m;
- 2) The ten-day average of daily filling speed shall be lower than 0.15 m/d;

- 3) The ten-day average of daily filling speed may be increased appropriately through experiments and demonstration, but shall not exceed 0.2 m/d.

6.4.6 The requirements for construction quality control by the design of filling-siltation damming of ash and slag are as follows:

- 1 In respect of filling quality of ash and slag dam body, inspections shall be conducted during construction to see whether concentration of slurry, filling speed and filling criterion all meet the design requirements.

- 2 During construction, the horizontal and settlement displacements of dam bodies shall meet the design requirements, and be free of abrupt changes.

- 3 During construction, the seepage volume of dam bodies shall be monitored on regular basis so as to understand the drainage effect of drainage facilities disposed in dam bodies, and the solidifying conditions of filled ash and slag.

- 4 Prior to construction, measures concerning safety management, protection and emergency treatment shall be worked out.

- 5 In respect of the filling quality of ridges, the compactness of ridges shall not be less than 0.95; in rainy areas, the geotextile bags filled with ash and slag can be employed for filling the ridges.

- 6 The filling-siltation damming of ash and slag can be carried out at daily average temperature of 5°C and above and shall be suspended when daily minimum temperature is below 0°C.

- 7 The height of dam bodies that are hydraulically filled with ash and slag shall have 3%–5% redundant height for settlement, and the specific percentage shall be determined in accordance with the design requirements.

- 8 The selection of ash samples to be tested during construction

shall meet the following requirements:

- 1) Each plot shall have at least three sets of dry density testing points at representative locations, with each set including upper, middle and lower original ash samples;
- 2) The sampling shall be carried out 24 h after the plot is compacted by plate vibroflots.

### 6.5 Foundation of Subdam

6.5.1 If the deposited ash and slag constituting subdam base meet the following requirements, subdam can be constructed directly on the bank of deposited ash and slag:

- 1 Ash slurry has been dumped evenly in dam front and coarse particles have deposited;
- 2 The dry bank is long enough to ensure the deposited ash and slag is not saturated;
- 3 Having been rolled, the deposited ash and slag has a bearing capacity not less than 100 kPa.

6.5.2 If subdams cannot constructed directly on the banks of deposited ash and slag, the ground bases shall be treated properly. The treatment measures shall be determined according to the characteristics of ash and slag, height of subdam, seismic fortification intensity, construction conditions through technical and economic comparison. The ground bases can be reinforced by filling with rock and rolling, and when necessary, can be treated further with other methods, such as reinforced geotextile, geogrid, sand drains, vibro-replacement stone columns, vibrated and compacted ash-lime piles after dedicated argumentation.

6.5.3 The method of vibro-replacement stone column used in treating the ground bases of ash-slag dams shall meet the following

requirements.

1 The ground bases can be treated using the method of vibro-replacement stone column in the following cases:

- 1) The subdam is far away from primary dam and preceding subdam, and its ground base is constituted by layers of fine-grained and loose ash and slag, thereby failing to meet the requirements for the stability of dams;
- 2) The location of phreatic line is high and the strength of ash and slag is low, thereby failing to meet the requirements for anti-liquefaction of dam bodies.

2 The characteristic values of bearing capacity of the ground bases treated using the method of vibro-replacement stone column shall be determined in accordance with the following stipulations:

- 1) For Class I dam bodies, the characteristic values shall be determined through load tests on composite base-ground;
- 2) For Class II and III dam bodies, the characteristic values shall be calculated according to load tests on individual columns and the ash and slag among columns using Formula (6.5.3-1) and Formula (6.5.3-2) as follows:

$$f_{SP} = a_c f_{pk} + (1 - a_c) f_{sk} \quad (6.5.3-1)$$

$$a_c = d^2 / d_e^2 \quad (6.5.3-2)$$

When the columns are arranged in equilateral-triangle pattern,  $d_e = 1.05S$ ;

When the columns are arranged in rectangular pattern,  $d_e = 1.13(S_1 S_2)^{1/2}$ ;

When the columns are arranged in square pattern,  $d_e = 1.13S$ .

Where:

$f_{SP}$  — Characteristic values of the bearing capacity of a composite ground-base, kPa;

$f_{pk}$ —Characteristic values of the bearing capacity of individual columns, kPa;

$f_{sk}$ —Characteristic values of the bearing capacity of ash and slag among columns, kPa;

$a_c$ —Area ratio of columns to ash and slag;

$d$ —Diameter of column, m;

$d_e$ —Diameter of equivalent influent circle of an individual column, m;

$S, S_1,$  and  $S_2$ —Distance, longitudinal distance and latitudinal distance between two adjacent columns, m.

3) Where the on-site load test data is not available, the characteristic values of bearing capacity of composite ground bases can be determined using Formula (6.5.3-3) as follows:

$$f_{SP} = [1 + a_c(n-1)]f_{sk} \quad (6.5.3-3)$$

Where:

$n$ —Stress ratio of column to ash-and-slag, which can be 2–4 if actually measured data is not available, with the larger value being suitable for low bearing capacity of natural soil bases, and the smaller one for high bearing capacity of natural soil bases.

The characteristic values of the bearing capacity of ash and slag among columns can be substituted with that of natural soil base.

3 The compression and deformation modulus of composite ground bases can be calculated using the following formulas.

1) Compression modulus of composite ground base:

$$E_{SP} = [1 + a_c(n-1)]E_S \quad (6.5.3-4)$$

Where:

$E_{SP}$ —Compression modulus of composite ground base, MPa;

$E_S$ —Compression modulus of ash and slag among columns,

which can be substituted with the compression modulus of natural soil as well, MPa.

2) Deformation modulus of composite ground base:

$$E_{OP} = \frac{E_O A_O + (A - A_O) E_P}{A} \quad (6.5.3-5)$$

Where:

$E_{OP}$ —Deformation modulus of composite ground base, MPa;

$E_O$ —Deformation modulus of ash and slag among columns, MPa;

$E_P$ —Deformation modulus of columns, MPa;

$A_O$ —Effective area of ground among columns in the treatment of individual columns,  $m^2$ ;

$A$ —Area of ground among columns undertaken by individual columns,  $m^2$ .

4 The indicators of shearing strength of composite ground bases can be calculated using Formula (6.5.3-6) – Formula (6.5.3-8) as follows:

$$\tan\phi_{SP} = a_c \mu_P \tan\phi_P + (1 - a_c \mu_P) \tan\phi_S \quad (6.5.3-6)$$

$$C_{SP} = (1 - a_c \mu_P) C_S \quad (6.5.3-7)$$

$$\mu_P = \frac{n}{(n-1)a_c + 1} \quad (6.5.3-8)$$

Where:

$\phi_{SP}$ —Internal friction angle of composite ground base, ( $^\circ$ );

$C_{SP}$ —Cohesive force of composite ground base, kPa;

$\phi_P$ —Internal friction angle of column, ( $^\circ$ );

$C_S$ —Cohesive force of the ash and slag among columns, kPa;

$\phi_S$ —Internal friction angle of ash and slag among columns or undisturbed soil, ( $^\circ$ );

$\mu_P$ —Stress concentration factor.

5 The arrangement of vibro-replacement stone columns shall be determined according to the stability of dam bodies, however, with at least three rows of columns arranged outside the upstream and downstream toes.

6 The diameters of vibro-replacement stone columns are related to the compactness of ash and slag, and the power of vibroflots. For vibroflots with a rated power of 75 kW, the diameters of columns can be 1.0 m–1.2 m.

7 The distances between two adjacent vibro-replacement stone columns shall be determined according to the loads of columns and the bearing capacity of ash-slag dam foundation. However, as the distance between two adjacent vibro-replacement stone columns is related with many factors such as grain size distribution of ash and slag, required compactness and the power of vibroflots, it shall be determined through on-site experiment. Vibroflots with a rated power of 75 kW should be employed for vibratory treatment of ash and slag dam base, and the distance between columns can range 1.8 m–2.5 m generally, or be determined using Formula (6.5.3-9) as follows:

$$S = \beta \psi \sqrt{\frac{1 + e_0}{e_0 - e_1}} d \quad (6.5.3-9)$$

$$e_1 = e_{\max} - D_r (e_{\max} - e_{\min}) \quad (6.5.3-10)$$

Where:

$S$ —Distance between columns, m;

$\beta$ —Shape coefficient, which can be 0.952 for triangle arrangement, 0.886 for square arrangement, and 1.254 for staggered arrangement;

$\psi$ —Empirical coefficient determined taking into account the fact that partial particles are washed away, which can be

1.00 for coarse sand, 0.90 for medium sand, 0.80 for fine sand, and 0.7 for silty sand, the empirical coefficient for ash and slag can be determined with reference to that for silty sand;

$d$ —Diameter of column, m;

$e_0$ —Natural void ratio of sand soil;

$e_1$ —Void ratio to be reached after ground base treatment;

$e_{\max}$ —Maximum void ratio of natural soil;

$e_{\min}$ —Minimum void ratio of natural soil;

$D_r$ —Relative compactness to be reached after ground base treatment, which can be 0.70-0.85.

8 The design lengths of vibro-replacement stone columns shall be determined in accordance with the following stipulations:

- 1) If the bearing stratum beneath dam foundations are relatively shallow, the design lengths shall be determined according to the burial depth of bearing stratum. Generally, the tips of columns shall be driven into the bearing stratum no less than 500 mm.
- 2) If the ground base is so deep that the tips of columns cannot be driven into the bearing stratum, the lengths of columns shall be determined according to the thickness of liquefied stratum. The columns shall be driven into the non-liquefied stratum no less than 2 m.
- 3) The lengths of columns should be not less than 4 m but not more than 18 m.

9 The vibro-replacement stone columns can be made of crushed stone, cobble stone, gravel, coarse sand or mining refuse with a silt content no more than 5%, or other rigid non-corrosive materials with stable performance. Severely weathered rock materials liable to

soften are strictly unacceptable. The crushed stone with a particle sizes ranging from 3 cm-10 cm and no less than 15 cm in maximum is usually preferred.

10 The heads of columns at some height on top of treatment layers of ground bases, about 1.5 m high in case of 75 kW vibroflots, which are not stably compacted shall be rolled using heavy-duty vibratory rollers until the required compactness is reached.

11 Cushion layers of compacted (vibrated) crushed stone shall be laid above the vibro-replacement stone columns. The thickness of crushed stone constituting the cushion layers can be 400 mm when the distance between columns is less than 2.0 m, and 500 mm when the distance between columns is greater than 2.0 m. The cushion layers shall extend beyond the outer edges of dam toes 500 mm with a compactness greater than 0.95.

In addition, a layer of non-woven geotextile and a layer of geogrid shall be laid between the vibro-replacement stone columns and the cushion layers from bottom to top.

## **7 Phreatic Lines of Dam Bodies**

### **7.1 Control of Phreatic Line of Dam Bodies**

7.1.1 The position of phreatic lines shall be determined through seepage calculation or experiments.

7.1.2 The phreatic lines shall be lowered by taking engineering measures described below:

1 The primary dams should be permeable dams or impermeable dams with seepage drains in dam front;

2 The subdams should be impermeable dams which may equipped with seepage drainage facilities in the front or at the bottom;

3 The ash slurry is discharged evenly in the front so as to maintain sufficient length of dry bank.

### **7.2 Seepage Calculation of Dam Bodies**

7.2.1 Seepage calculation shall cover seepage fields including primary dam, subdams and ground base, derive the positions of phreatic lines and downstream overflowing points, profile of equipotential lines, seepage velocity and flowrate, and provide basis for stability calculation of dam bodies, arrangement of seepage facilities and stability analysis of seepage.

7.2.2 Calculations and studies shall be conducted on seepage of dam bodies under the following work conditions when the ash surface of ash yard is limited ash storage elevation:

1 Stable seepage under the condition of limited length of dry bank;

2 Stable or non-stable seepage under the condition of limited length of dry bank by taking into account design flood;

3 Stable or non-stable seepage under the condition of limited length of dry bank by taking into account check flood;

4 Different types and positions of seepage facilities, and seepage facilities being blocked.

7.2.3 The seepage should be calculated and studied through mathematical modeling by means of calculation programs, or can be tested through electric analogue. Two-way seepage can be used for studying board valley, plain and beach ash yards. Three-way seepage can be used for studying V-shaped, U-shaped and narrow and deep valley ash yards. However, in design of subdam heightening, comparison should be made against actually measured phreatic lines.

7.2.4 During design of primary dams, the seepage coefficient of ash and slag of other similar ash yards is suitable for adoption, and for subdam heightening, the above coefficient shall be determined through sampling and testing on ash and slag deposited where the subdam is to be built.

## 8 Calculation and Analysis of Dam Bodies

### 8.1 General Provisions

8.1.1 The verification involves calculation of anti-sliding stability of dam bodies and static and dynamic analysis on the possibility of their liquefaction, which can be selectively carried out according to class of dam, seismic fortification intensity of the area where the dam is located, and specific design phase.

8.1.2 The stability of primary dams shall be verified in accordance with the stipulations described below:

1 The stability of primary dams shall be verified taking into account subdam heightening;

2 Ash yards shall be planned with reference to data of similar ash yards in the phase of feasibility study with the verification of stability being omitted;

3 In the phase of design of ash yards, the anti-sliding stability of primary dams and heightened dam shall be calculated in line with the mechanical properties of ash and slag in the similar ash yards, with the static and dynamic analysis being omitted.

8.1.3 The stability of heightened subdams shall be verified in the phase of preliminary design in accordance with the following stipulations:

1 The design of subdam heightening shall cover verification of stability of individual subdams, as well as that of the entire dam body including ground base and primary dam;

2 In areas where the seismic fortification intensity is 7 degree, the design of subdam heightening shall be based on static and

dynamic analysis; while in areas where the seismic fortification intensity is 8 degree, the same shall be based on specific technical and economical demonstration;

3 When carrying out static and dynamic analysis in the design of subdam heightening, test data on the physical, static, and dynamic properties of deposited layers of ash and slag in ash yard as well as on-site test (standard penetration test and static cone penetration test) data shall be available to help to judge the engineering properties of ash and slag comprehensively.

8.1.4 Seepage stability of dam bodies shall be calculated and shall meet the requirements for permissible critical gradient and seepage stability so as to prevent soil from flowing and piping.

## 8.2 Calculation of Anti-sliding Stability of Dam Bodies

8.2.1 The calculation shall be based on the type of dam, construction material of dam body, mechanical properties of soils constituting the ground base and various operating conditions, so as to verify whether the stability of dam body can meet the requirements for anti-sliding safety factor and to determine a reasonable cross section for dam body.

8.2.2 The operating conditions for calculating anti-sliding stability of slopes at both sides of dam body shall be as per Table 8.2.2.

**Table 8.2.2 Combined operating conditions for calculating anti-sliding stability of slopes at both sides of dam bodies**

Slope	Operating Condition	Valley Ash Yard	Beach Ash Yard	Plain Ash Yard
Upstream slope	Normal operating condition	Ash dam built + no ash storage	Embankment built + storing no ash storage + design flood (tide) level outside embankment	Embankment built + storing no ash storage

Table 8.2.2 (continued)

Slope	Operating Condition	Valley Ash Yard	Beach Ash Yard	Plain Ash Yard
Upstream slope	Abnormal operating condition	Ash dam built + no ash storage + check flood	Embankment built + no ash storage + check flood (tide)level outside embankment	
Downstream slope	Normal operating condition	Limited ash storage elevation + limited length of dry bank	Limited ash storage elevation + limited length of dry bank + average low water level outside embankment	Limited ash storage elevation + limited length of dry bank
		Limited ash storage elevation + limited length of dry bank + design flood	Limited ash storage elevation + limited length of dry bank + design flood inside embankment	Limited ash storage elevation + 0 m long dry bank
	Abnormal operating condition	Limited ash storage elevation + limited length of dry bank + check flood	Limited ash storage elevation + limited length of dry bank + check flood inside embankment	
		Limited ash storage elevation + limited length of dry bank + earthquake	Limited ash storage elevation + limited length of dry bank + average water level outside embankment + earthquake	Limited ash storage elevation + limited length of dry bank + earthquake

8.2.3 The anti-sliding stability should be calculated using Swedish circle method or Bishop's simplified method. For rockfill dams, polyline method can be used. If there are soft interlayers in ground base, modified circle method can be used. When using Bishop's

simplified method, the minimum permissible safety factor should be 10% greater than specified.

8.2.4 The anti-sliding stability should be calculated using gross stress method. When dissipation of pressure in pore water and increase of strength is required, effective stress method can be used. The methods for measuring the strength index employed in such calculation shall be consistent with calculation method. See Appendix A for methods for measuring the shearing strength index.

8.2.5 The anti-sliding stability of dam body under earthquake can be calculated using quasi-static method taking into account seismic inertia force. The seismic inertia force shall be determined in accordance with DL 5073.

### 8.3 Static and Dynamic Analysis for Dam Bodies

8.3.1 When designing subdam heightening project located in areas where seismic fortification intensity reaches 7 degree or above, designers shall conduct static and dynamic analysis to judge the possibility that dam bodies and ground bases would liquefy, to determine the liquefaction range, and to evaluate the earthquake resistance after subdams are heightened.

8.3.2 The static and dynamic analysis can be conducted through mathematical modeling using gross stress method or effective stress method.

The gross stress method in which all analysis and experiments are always based on gross stress is to judge the liquefaction ranges of dam bodies by calculating the dynamic shear stress ratios at various positions, that is, by comparing the actual dynamic shear stress ratios  $(\tau/\sigma')_c$  at various positions under earthquake with the test dynamic shear stress ratios  $(\tau/\sigma')_t$  that have to be reached for liquefaction to

occur.

The effective stress method is to judge on the basis of effective stress the possibility of liquefaction at various positions of dam bodies as well as the process of liquefaction by analyzing the increase of pore water pressure during earthquake with 100% pore water pressure as a judge criterion for liquefaction occurrence. The law whereby the pore water pressure of ash and slag occurs during cyclic shearing of effective stress method shall be demonstrated by dedicated experiment and demonstration.

See Appendix B for the static and dynamic analysis and calculation principles by using gross stress method and the experiment data required.

## 9 Dam Safety Monitoring System

### 9.1 General Provisions

9.1.1 The dam bodies shall be equipped with phreatic-line and displacement monitoring systems according to dam class, height, type, topography, and geology. Such monitoring systems shall be provided with all valley ash yards, and be provided with plain and beach ash yards only when they need to be heightened.

9.1.2 The monitoring systems shall be completed and accepted simultaneously with dam bodies. The monitoring facilities shall have proper protective measures.

### 9.2 Phreatic-line Monitoring System

9.2.1 Phreatic-line monitoring system shall include the following facilities:

- 1 Scales for water level monitoring;
- 2 Instruments for measuring length of dry bank;
- 3 Piezometers or pore water pressure gauges buried in dam;
- 4 Instruments for measuring water level in piezometers.

9.2.2 For valley ash yards, the pressure measuring points shall be laid along the axes of dam at maximum dam height and at positions typical of phreatic line variations in no less than 3 rows. The measuring points in the direction perpendicular to the axes of dams shall cover upstream seepage points, intermediate points, the tops of primary dams and subdams, downstream overflowing points and other typical positions, and should not be less than 4 points.

9.2.3 If phreatic-line monitoring systems are required for plain and beach ash yards, they shall be arranged in no less than 2 rows each containing no less than 3 points.

### 9.3 Displacement Monitoring System

9.3.1 It is necessary to monitor dam face for its horizontal displacement and settlement and the two types of monitoring marks can be disposed on same stake.

9.3.2 The arrangement of stakes shall comply with the stipulations described below:

1 For valley ash yards, the stakes shall be arranged at maximum dam height, at drainage pipes and at the cross sections of areas where topography and geology changed a lot and the cross sections to be monitored shall not be less than 3, with at least 3 marks arranged at the downstream abutments of dam tops and the outer edges of berms on each section. The marks at equal positions of various cross sections shall be arranged in a line for convenience of visual monitoring.

2 When displacement monitoring systems are required for plain and beach ash yards, at least 2 cross-sections for monitoring should be arranged according to ground bases and embankment heights.

9.3.3 The working base points shall be arranged on rocks or solid earth which make the monitoring of marks easy. Check base points can be provided if necessary. When triangulation network method is employed, there can be two working base points. When collimation line method is used for valley ash yards, one working base point should be arranged on the extended line of each longitudinal row of marks at both banks of dam bodies.

## 10 Requirements for Construction Quality Control

### 10.1 General Requirements

10.1.1 After the ground bases and bank slopes of primary dams and subdams are cleaned, there shall be survey engineering personnel participating in examining the foundation trenches. Only when ground base treatment and the concealed works are accepted as qualified can subsequent construction processes be carried out.

10.1.2 The ground bases and bank slopes of dams shall be excavated in accordance with the design requirements for excavating range, gradient and height.

10.1.3 The bank slopes of abutments shall be excavated and cleaned from top to bottom at one time, and shall not be excavated from bottom to top or using other methods that result in overhung rocks.

10.1.4 If the dam bodies cannot be filled immediately after the cohesive-soil ground bases are excavated, protective layers or other protective measures should be taken and then be removed when filling the dam bodies. During construction in winter, the thicknesses of protective layers shall allow for the effect that ground base soil is frozen.

10.1.5 The ranges of areas near dams from which construction material are taken shall meet the requirements described below:

1 For valley ash yards, it is not acceptable to take construction materials from areas at the upstream and downstream of abutments. When necessary, such materials must be taken from areas 50 m away

from the planned toe line of dam body so as to keep a stable gradient;

2 When it is necessary to take soil from outside the toe, the soil shall be taken at positions away from the toe line more than three times of dam height with a depth no more than half of dam height, otherwise the distance from the toe shall be determined by calculation;

3 When ash and slag has to be taken in ash yards, the pits shall be 40 m away from the toes with depths no more than 5 m.

10.1.6 During rainy seasons, the cohesive-soil dams shall be constructed in accordance with the following requirements:

1 Rains shall be forecasted properly. Prior to rains, the loose surface soil shall be compacted rapidly using rolling devices, and the filling fields shall be kept flat, thereby preventing rain water from infiltrating and accumulating. After rains, the filling fields shall be appropriately dried under sunshine or treated with other methods;

2 The large-sized construction equipment should leave the filling fields prior to rains;

3 The dam faces shall be carefully protected during rains or after rains, and must not be trampled by people or ruined by vehicles.

10.1.7 Appropriate protective measures shall be taken when dam bodies being constructed at temperature below zero, and the following major items shall be checked:

1 Whether anti-freeze measures have taken for the filling fields;

2 Whether the compacted soil layers are frozen;

3 Whether the snow covering the filling fields is removed;

4 The ambient air temperature, soil temperature and wind speed shall be observed and recorded;

5 During spring, the quality of soil layers within freezing depth

shall be rechecked.

10.1.8 The construction quality shall be examined and accepted in accordance with GB 50286, DL/T 5129, SDJ 280, SL 60, and SL 274.

## 10.2 Requirements for Filling

10.2.1 The filling of dam bodies shall be strictly controlled based on the compactness parameters determined through construction experiments.

10.2.2 During the construction of dam bodies, various processes shall be joined mutually, organized closely, executed in stages, arranged orderly, so as to evenly raise filled material and reduce joints. Soil shall be extended outwards sequentially, laid evenly, leveled promptly and rolled in the direction parallel to dam axes instead of in the direction perpendicular to dam axes.

10.2.3 For homogeneous earth-filled dams, sand-gravel-filled dams, and stone-ballast-filled dams, their dam slopes should be paved with surplus soil at the upstream and downstream of dam body cross sections, and should be cut down to designed cross sections.

10.2.4 The impermeable bodies made of earth shall be filled simultaneously with dam bodies and inverted filters, with various materials being paved in sequence.

10.2.5 The filling quality of dam bodies shall be controlled by checking the following major items:

- 1 Quality control targets of various construction materials;
- 2 Surface conditions of compacted soil before each new layer of soil, for example, the wetting degree of watered cohesive soil;
- 3 Thickness of laid soil and implementation of rolling parameters;
- 4 Compatibility between water content and weight of roller, and presence of interlayer plain faces, shearing damage, spring soil,

pressure leakage, pressure shortage, and cracks in soil layers;

5 Joining of dam bodies with ground bases, bank slopes, rigid structures and buried pipes beneath dams, and treatment of longitudinal and latitudinal junctions;

6 The construction quality of the construction materials at various parts of dam body;

7 Gradients of dam slopes;

8 Implementation of construction measures for winter and raining seasons.

10.2.6 The cushion layers of protective slopes shall meet the requirements for material and dimensions. When block stone or other surface layers being laid, cushion layers must not be damaged.

10.2.7 The construction of protective slopes made of dry stone masonries shall meet the following requirements:

1 The rock material used for protective slopes shall meet the design requirements for quality and dimensions, and cracked or weathered stones shall not be employed;

2 Stone blocks less than 30 cm long shall not be used contiguously more than 4, and must have T-shaped stones at both ends;

3 In masonry works, elongate stone blocks shall be laid vertically, rather than horizontally;

4 Protective slopes shall be constructed from bottom to top with stones being laid with staggered joints, stably stuffed up, tight and compact with a flat surface.

10.2.8 The protective slopes built of stone masonry shall meet the requirements for dry stone masonry as well as the following requirements:

1 They shall be constructed by bed mortar method;

2 The raw material, mixture ratio and strength of mortar shall meet the design requirements. The mortar shall be stirred immediately

before usage. The unused mortar which has initially solidified shall be disposed as waste;

3 The joints of stone masonry shall be filled up with cement mortar with lower water-cement ratio.

10.2.9 The construction of protective slopes built of precast concrete slabs (blocks) shall meet the following requirements:

1 The strength of precast concrete slabs (blocks) shall meet the design requirements;

2 The precast concrete slabs (blocks) shall be laid evenly and stably with tight and regular joints.

10.2.10 The geotextile inverted-filters and impermeable geomembrane shall be laid and accepted in accordance with the following requirements:

1 The geosynthetics shall meet the design requirements for type, specifications, physical-mechanical properties, permeability and be subject to sampling inspections if they are delivered to the construction sites in batches. They shall undergo cosmetic inspections to make sure there are no holes or breaks prior to laying;

2 The base faces beneath geosynthetics shall be flat without sharp corners and tree roots to prevent the geosynthetics from being damaged during construction;

3 The geotextile can be joined by sewing or overlapping method. In case of sewing, “overseam stitching” or “T” seam stitching should be employed for geotextile with at least 150 N strong nylon threads. In case of overlapping, the overlapping width can be 300 mm;

4 The geomembrane shall be overlapped by bonding with the width of bonding seam being not less than 10 cm. The bonded geomembrane shall be protected against damage, and the binding quality be examined;

5 The geosynthetics shall be paved with covering materials in

time, so that it cannot be exposed for a period longer than specified in the product technical specification;

6 The covering material should be laid by forward unloading method. Slopes should be paved from bottom to top. The unloading height should not be greater than 1.5 m for sandy gravel, not greater than 0.5 m for rock materials with sharp corners. The layers must wear soft-soled shoes.

### 10.3 Requirements for Quality Control

10.3.1 The checking items and sampling times required for compacting dam bodies shall be as specified in Table 10.3.1.

**Table 10.3.1 Checking items and sampling times  
required for compacting dam bodies**

Construction Material	Position	Checking Item	Sampling Times
Cohesive soil	Rammed edges and corners	Dry density and water content	2–3 times per layer
	Rolled dam bodies		Once per 200 m <sup>3</sup> –500 m <sup>3</sup>
Gravel soil	Rammed edges and corners	Dry density, water content and gravel content	2–3 times per layer
	Rolled dam bodies		Once per 200 m <sup>3</sup> –500 m <sup>3</sup>
Inverted filter	Rolled dam bodies	Dry density, grain size analysis and silt content	Once per 200 m <sup>3</sup> –500 m <sup>3</sup>
Rockfill	Rolled dam bodies	Porosity and grain size analysis	Once per 10 000 m <sup>3</sup>
Masonry	Rolled dam bodies	Porosity	Once per 10 000 m <sup>3</sup>
Stone ballast	Rolled dam bodies	Dry density and water content	Once per 400 m <sup>3</sup> –1000 m <sup>3</sup>
Ash and slag	Rolled dam bodies	Dry density and water content	Once per 200 m <sup>3</sup> –500 m <sup>3</sup>

10.3.2 The final as-built acceptance of dam bodies shall include the acceptances and as-built acceptances of all subworks during construction. The deviations of key construction items at the time of acceptance shall be within the permissible ranges as specified in Table 10.3.2.

**Table 10.3.2 Permissible deviations specified for construction acceptance**

No.	Item	Permissible Deviation
1	Elevation of the top of as-built dam	$\leq 20$ cm, not less than design elevation
2	Elevation of the center of pipeline buried in dam body	Can be less than 5 cm, but must not be greater than design elevation
3	Length of pipeline buried in dam body	Must not be less than design length
4	Width of dam top	$\pm 10$ cm
5	Gradient of dam body	$\pm 2\%$
6	Thickness of protective slope	$\pm 15\%$
7	Dry density	The qualification rate shall not be lower than 90%, while unqualified dry density shall not be less than 95%
8	Difference between actual water content and optimal water content	$-4\% - +2\%$
9	Porosity of rolled (un-rolled) rockfill material	$+2\%$ ( $+5\%$ )
10	Gradient of cut bank slopes	Not sharper than design gradients
11	Axis of dam	Shall be measured and designed based on Class II accuracy of traverse survey

## 11 Requirements for Operation Management

### 11.1 General Provisions

11.1.1 The above requirements shall be specified explicitly in design documents.

11.1.2 Ash storage yards shall be provided with management stations equipped with necessary maintenance equipment, vehicles and communication facilities. The management stations shall include resting rooms for staff on duty, repair rooms, warehouses, roads and essential domestic installations.

11.1.3 Dedicated personnel shall be appointed in charge of the operation and routine maintenance of ash yards, shall have the following responsibilities:

- 1 To monitor phreatic lines and the evenness of ash discharged in dam front as well as its deposition;
- 2 To monitor the functioning of drainage system, variations of water level in ash yards and variations in length of dry banks;
- 3 To monitor the operation of ash water recovery systems;
- 4 To record and analyze the operation conditions regularly, and to report and tackle the abnormalities occurred immediately.

### 11.2 Engineering Management of Ash Yard

11.2.1 Engineering management ranges shall be defined for ash yards in junction with natural geographical conditions and local situation for the purpose of ensuring safe and normal operation of ash yards. The engineering management range includes areas surrounding

various buildings and structures in ash yards, such as ash dams, drainage systems, flood discharging systems and observation facilities as well as areas within the boundary of land requisitioned for ash yards. The engineering management range shall meet the following stipulations:

1 At least 150 m away from land requisition boundary at the upstream and at least 200 m at the downstream for Class I and Class II valley ash yards; at least 100 m away from land requisition boundary at the upstream and at least 150 m at the downstream for Class III ash yards;

2 Bounded by first watersheds at both ends of the dam, or at least 100 m away from both ends of the dam;

3 For Class I, II, and III ash yards, joined with the end lines of management ranges of the dam at both the upstream and downstream;

4 For plain and beach ash yards, at least 50 m away from the outer edges of drainage ditches outside the ash yards.

11.2.2 It is prohibited to carry out any activities within the management ranges of dams that may endanger the dams, such as demolition, well drilling, rock excavation, mining and soil excavation. It is prohibited to conduct within the range of ash yards any activities that may result in soil erosion, such as deforestation and land reclamation on steep slopes.

### 11.3 Monitoring of Dam Bodies and Phreatic Lines

11.3.1 The monitoring shall cover elevation of ash surface, elevation of water stored, length of dry banks, water level at each pressure measuring point in dam bodies and water level at the downstream and weather conditions.

11.3.2 The phreatic lines should be monitored once a month during

normal operation, once per day when the water level in the ash yards rises during flood periods, and more frequently after earthquakes or when seepage occurs. The phreatic lines shall be measured twice by different persons, and the deviation shall not exceed 2 cm.

11.3.3 People shall draw the phreatic lines based on the monitored data, and inspect downstream slope faces for leakage or wet pieces at the same time.

11.3.4 People shall monitor the quantity and quality of the seepage water of drainage prisms or seepage drainage pipes beneath dams and shall take appropriate measures and intensify the monitoring when seepage water increases sharply or becomes muddy.

11.3.5 The settlement monitoring points buried in dam bodies should be measured once a month in the initial stage, shall be measured more frequently during floods, after earthquakes or when slope collapses are detected. People shall calculate the settlement and horizontal displacement of dam bodies based on the monitored data, can reduce measurements when the settlement and displacement become almost stable. The cracks or potential landslides found in dam bodies shall be immediately reported and tackled.

11.3.6 The dam slopes shall be monitored for partial landslides and situations that the dam slopes are washed away by ash slurry water from outlets of ash pipes, leakage from ash pipes or converged rainwater shall be handled immediately.

11.3.7 The ash dams shall be monitored for ash storage elevations in the front of dams, and must be heightened in time or stop storing ash and slag when limited ash storage elevations are reached.

#### 11.4 Monitoring of Ash and Slag Discharging

11.4.1 The ash and slag shall be discharged evenly in the front of

dams to form dry banks. Where it is impractical to discharge ash and slag in the front of dams, relative measures shall be taken to direct and deposit ash and slag in the front of dams, and form dry banks.

11.4.2 Measures, such as diverting the flow of ash slurry, shall be taken when necessary to humidify the surfaces of dry banks, thereby preventing ash from scattering and causing pollution.

11.4.3 The ash discharging pipes shall be switched, or the positions of ash outlets be adjusted as necessary to discharge ash slurry water evenly and avoid scour to the dam slopes and dam toes.

11.4.4 The ash discharging pipes shall be monitored for blockage and leakage which shall be dealt with immediately when found.

### 11.5 Drainage System Monitoring

11.5.1 The drainage systems of ash storage yards must be kept unobstructed, clarified ash water and flood shall be discharged promptly, so as to keep the water level in ash yards under control and maintain the limited length of dry bank (which generally is not less than 150 m for valley ash yards) according to the design requirements.

11.5.2 People must adjust the water level based on climatic conditions and clarification of ash slurry water by blocking, adding stop logs on or putting covers on the openings of drainage wells or other types of drainage facilities if necessary. The clarified ash water shall be discharged continuously and recycled.

11.5.3 The components of drainage facilities, such as plugs for openings, precast stop logs and covers, shall be complete and in good condition.

11.5.4 The content of suspensions in clarified ash water shall meet the requirements for ash water recycling or waste water drainage.

11.5.5 When ash yards are filled up and out of use, they shall be

covered with soil in time. For valley ash yards and the beach ash yards in which flood may be collected, complete drainage systems shall be retained and appropriate capacity be reserved for flood control as required by design.

## Appendix A (Normative)

### Methods for Measuring Shearing Strength Index and Selection Thereof

A.1 See Table A.1 for methods for measuring shearing strength index.

**Table A.1 Methods for measuring shearing strength index**

Methods for Calculating Shearing Strength	Type of Soil	Instrument Employed	Test Method	Strength Index	Initial Condition of Samples
Gross stress method	Non-cohesive soil	Direct shear meter	Consolidated quick shear test	$C_{CU}$ $\phi_{CU}$	1. Construction material of dam bodies (1) The water content and density are same as original condition. (2) The material below phreatic lines and water level needs to be pre-saturated. (3) The test stress is same as the stress of dam body. 2. Ash and slag Take original ash and slag as sample, while other conditions are same as those for dam bodies. 3. Dam foundation soil Undisturbed soil is used as sample
		Triaxial test meter	Consolidated undrained (CU) shear test		
	Cohesive soil	Direct shear meter	Consolidated quick shear test		
		Triaxial test meter	Consolidated undrained (CU) shear test		
	Ash and slag	Direct shear meter	Consolidated quick shear test		
		Triaxial test meter	Consolidated undrained (CU) shear test		

Table A. 1 (continued)

Methods for Calculating Shearing Strength	Type of Soil	Instrument Employed	Test Method	Strength Index	Initial Condition of Samples
Effective stress method	Non-cohesive soil	Direct shear meter	Slow shear test	$C_{CD}$ $\phi_{CD}$	1. Construction material of dam bodies (1) The water content and density are same as original condition. (2) The material below phreatic lines and water level needs to be pre-saturated. (3) The test stress is same as the stress of dam body. 2. Ash and slag Take original ash and slag as sample, while other conditions are same as those for dam bodies. 3. Dam foundation soil Undisturbed soil is used as sample
		Triaxial test meter	Consolidated drained (CD) shear test		
	Cohesive soil	Direct shear meter	Slow shear test	$C'$ $\phi'$	
		Triaxial test meter	Consolidated undrained (CU) shear test while measuring the pore water pressure		
	Ash and slag	Direct shear meter	Slow shear test	$C_{CD}$ $\phi_{CD}$	
		Triaxial test meter	Consolidated drained (CD) shear test		

Notes:  $C$ —Cohesive force, kPa;  $\phi$ —Internal friction angle, (°).

## Appendix B (Informative)

### Calculation Principle and Required Test Data for Static and Dynamic Analysis by Using Gross Stress Method

**B.1** Seed-Idriss simplified procedure [its formula is  $(\tau_d/\sigma'_o)_t > (\tau_d/\sigma'_o)_c$ ] is suitable for judging liquefaction by using gross stress method. When comparison satisfies a certain safety coefficient (generally, it is 1.5), the soil is judged to have no liquefaction potential; otherwise it has.

$(\tau_d/\sigma'_o)_t$  is the ratio of dynamic shear stress that soil body can bear and is derived from cyclic load tests in labs. Its values vary with the types of ash and slag and their relative density, and are also related with such parameters as number of vibrations, consolidation ratio,  $K_c$  and so on. Where,  $\tau_d$  is the dynamic shear stress born by soil body when being subjected to specified times of constant cyclic loading;  $\sigma'_o$  is the average consolidation stress of soil body;  $K_c = \sigma_1/\sigma_3$ ,  $\sigma_1$  is the maximum principal stress,  $\sigma_3$  is the minimum principal stress.

$(\tau_d/\sigma'_o)_c$  is the ratio of dynamic shear stress for each part of dam body under the effect of design taphrogeny and is calculated by using static and dynamic analysis programs. Where,  $\sigma'_o$  is the average stress of dam body before earthquake that is obtained through static analysis,  $\tau_d$  is the maximum dynamic shear stress that is obtained through dynamic analysis.

**B.2** The nonlinear increment finite element analysis under plane strain is employed for static analysis. The nonlinear stress-strain

relationship of the construction material (of dam bodies) can be expressed by Duncan-Chang  $E-\mu$  model (eight parameters), or E-B model of Duncan et al (seven parameters). The parameters of models are obtained from experiments in which technical personnel simulates the construction process of a dam body, divides the whole dam into several layers in height with one load increment being increased for each layer added and analyzes each increment until the whole dam is completed. Calculations are carried out by computer programs of static analysis, and shall give the following results:

1 The average stress of various parts of a dam body before earthquake,  $\sigma'_0$ .

2 The maximum principal stress  $\sigma_1$  and the minimum principal stress  $\sigma_3$  of each part of a dam body, and their ratio  $K_c = \sigma_1/\sigma_3$ , which can provide reference for determining the value,  $(\tau_d/\sigma'_0)_t$  of each part of the dam body and judge thereby whether there is tension stress.

3 The shear stress level of each part under various operating conditions,  $S_L$ , that is, the ratio of actual shear stress to shearing strength of each part,  $\tau/\tau_L$ , which reflects the degree that the stress of dam body may bring about damage and is used to judge the locations where dam body may suffer shear failures.

**B.3** In dynamic analysis, the designers shall first determine “design taphrogeny”, that is, the ground motion travel-time curve of a dam site within a specified time or its characteristic parameters (such as maximum acceleration, response spectrum and earthquake intensity) that exceed a certain probability. However, as this task takes much time and effort, designers can now, by utilizing existing earthquake records, scale up or down the existing earthquake process curve based on the ratio of maximum earthquake acceleration value of local seismic fortification intensity to maximum value of existing

earthquake process curve and work out a travel-time curve of earthquake acceleration  $a$  that varies with time period  $\Delta t$  as the “design taphrogeny”.

Currently, the existing earthquake process curves in common use include QianAn aftershock records of 1976 Tangshan earthquake China, 1974 Piaoyang earthquake China, 1974 Haicheng earthquake China, 1976 Songpan earthquake China and 1940 El Centro earthquake USA, among which, the 1940 El Centro earthquake is highly adaptable due to its high frequency, great strength, long duration, coverage of various frequencies. The recommended maximum earthquake accelerations are shown in Table B.1.

**Table B.1 Recommended maximum earthquake acceleration**

Design Intensity	7	8	9	Remark
$a_h$	0.1 g	0.2 g	0.4 g	Taken from codes for seismic design of hydraulic structures
$a_{max}$	0.125 g	0.25 g	0.5 g	Recommended for calculations

As the duration of earthquake is mainly related to magnitude rather than design intensity, it is recommended to take a value greater than 20 s.

**B.4** Labs shall provide the dynamic properties of the material in question prior to dynamic analysis. The response characteristics of dam bodies under dynamic loads can be calculated by analyzing non-linear finite element dynamic response under the condition of plane strain. Such calculations can be carried out by using iterative method: firstly, postulate the dynamic shear modulus  $G$  and damping ratio  $\lambda$  of each part of the dam body; secondly, integrate the values in

each calculating period to calculate the unit displacement and dynamic shear strain amplitude  $\lambda_d$  of each part; thirdly, find out the dynamic shear modulus  $G$  and the damping ratio  $\lambda$  of each part based on the  $G/G_{\max}—\gamma_d$  and  $\lambda—\gamma_d$  curves that are obtained through experiments or already given; fourthly, compare them with the assumed  $G$  and  $\lambda$  values; and then calculate iteratively until calculation errors are within permissible ranges.

Calculations are carried out through computer programs of dynamic analysis, and shall give the following results:

- 1 Maximum dynamic shear stress for each part of dam body under input taphrogeny  $\tau_d$ ;
- 2 Resonant frequency of dam body under input taphrogeny;
- 3 Response acceleration of each node of dam body under input taphrogeny.

All these results may help to judge the safety of dam body in case of earthquakes.

**B.5** One feature of static and dynamic analysis by using gross stress is that calculation methods can be well compared with experiment methods. Prior to analysis and calculation, required test data on the physical properties, static and dynamic characteristics of various materials used for dam bodies and dam foundations shall be obtained through experiments conducted based on gross stress. The required test data are detailed below:

- 1 The material used for each part (including ground base soil, soil filled in dam bodies, ash and slag) of ash dams shall be tested in terms of their physical properties and static and dynamic characteristics, thereby providing calculation parameters. Where, for materials that are hard to liquefy, the static and dynamic parameters available for other projects can be adopted;

2 Physical experiments. Physical experiments cover basic physical properties (such as density, and water content), grain composition (such as grain size distribution, average grain diameter and unevenness coefficient), plasticity of cohesive soil (such as liquid limit and plastic limit), density of sandy soil, and permeability coefficient;

3 Static experiment. Static experiments include compaction tests and shear tests, which give out compactness index (such as compactness coefficient and compaction modulus) and strength indexes,  $\phi$  and  $C$  under the controlled dry density  $\rho_d$  that are determined based on actually measured data;

4 Experiment on deformation coefficient. The deformation coefficients are derived from static triaxial tests, which give out eight E- $\mu$  model parameters under  $\rho_d$ , that is, strength parameters  $C_d$  and  $\phi_d$ , modulus parameters  $K$ ,  $n$  and  $R_f$ , and Poisson ratio parameters  $d$ ,  $F$  and  $G$ , as well as seven E-B model parameters, that is,  $C_d$ ,  $\phi_d$ ,  $K$ ,  $n$ ,  $R_f$ , volume modulus parameter  $K_b$  and volume modulus index  $m$ ;

5 Experiment on dynamic characteristics. It includes experiments in respect of dynamic deformation characteristics and dynamic strength of soil. Such experiments are carried out under different control dry density  $\rho_d$ , consolidation ratio  $K_c$  and surrounding pressure  $\sigma_3$ . Experiment on dynamic characteristics is required to give out respectively the relationships between the maximum dynamic shear modulus  $G_{\max}$  of material and the surrounding pressure  $\sigma_3$ , between the ratio of dynamic shear modulus  $G$  to maximum dynamic shear modulus  $G_{\max}$  and the dynamic shear strain amplitude  $r_d$ , and between the damping ration  $\lambda$  and the dynamic shear strain amplitude  $r_d$ . Experiment on dynamic strength is required to give out the relationship between the dynamic shear stress ratio of material  $\Delta\tau/\sigma'_0$ ,

and the numbers of vibration cycles  $N$ , as well as strength indexes  $C_d$  and  $\phi_d$ ;

6 Experiment on dynamic characteristics is carried out by repeatedly applying sine wave loads and the correspondence between vibration magnitudes and equivalent vibration times and durations are listed in Table B.2.

**Table B.2 Correspondence between vibration magnitudes and equivalent vibration times and durations**

Magnitude	Equivalent vibration times, $N$	Vibration duration, $t$ (s)
5.5–6	5	8
6.5	8	14
7.0	12	20
7.5	20	40
8.0	30	60

7 Damage criteria for experiments.

- 1) Sample liquefies when vibrated pore water pressure  $U_d$  is equal to sample's surrounding consolidation pressure  $\sigma_3$ ;
  - 2) When full-sized strain reaches 5% with equal consolidation pressure ( $K_c = 1$ ) or the sum of residual deformation and elastic deformation reaches 10% with unequal consolidation pressure ( $K_c \neq 1$ ), sample is damaged.
-