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INDUSTRIAL DEVELOPMENT ORGANIZATION



Technical Guidelines for the  
Development of Small Hydropower Plants  
**DESIGN**

**Part 3: Engineering Geology**

**SHP/TG 002-3: 2019**



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**Part 3: Engineering Geology**

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Further recommendations and suggestions for application for the update would be highly welcome.

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## Foreword

The United Nations Industrial Development Organization (UNIDO) is a specialized agency under the United Nations system to promote globally inclusive and sustainable industrial development (ISID). The relevance of ISID as an integrated approach to all three pillars of sustainable development is recognized by the 2030 Agenda for Sustainable Development and the related Sustainable Development Goals (SDGs), which will frame United Nations and country efforts towards sustainable development in the next fifteen years. UNIDO's mandate for ISID covers the need to support the creation of sustainable energy systems as energy is essential to economic and social development and to improving quality of life. International concern and debate over energy have grown increasingly over the past two decades, with the issues of poverty alleviation, environmental risks and climate change now taking centre stage.

INSHP (International Network on Small Hydro Power) is an international coordinating and promoting organization for the global development of small hydropower (SHP), which is established on the basis of voluntary participation of regional, subregional and national focal points, relevant institutions, utilities and companies, and has social benefit as its major objective. INSHP aims at the promotion of global SHP development through triangle technical and economic cooperation among developing countries, developed countries and international organizations, in order to supply rural areas in developing countries with environmentally sound, affordable and adequate energy, which will lead to the increase of employment opportunities, improvement of ecological environments, poverty alleviation, improvement of local living and cultural standards and economic development.

UNIDO and INSHP have been cooperating on the World Small Hydropower Development Report since year 2010. From the reports, SHP demand and development worldwide were not matched. One of the development barriers in most countries is lack of technologies. UNIDO, in cooperation with INSHP, through global expert cooperation, and based on successful development experiences, decided to develop the SHP TGs to meet demand from Member States.

These TGs were drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of these TGs may be subject to patent rights. UNIDO and INSHP shall not be held responsible for identifying any such patent rights.

## Introduction

Small Hydropower (SHP) is increasingly recognized as an important renewable energy solution to the challenge of electrifying remote rural areas. However, while most countries in Europe, North and South America, and China have high degrees of installed capacity, the potential of SHP in many developing countries remains untapped and is hindered by a number of factors including the lack of globally agreed good practices or standards for SHP development.

These Technical Guidelines for the Development of Small Hydropower Plants (TGs) will address the current limitations of the regulations applied to technical guidelines for SHP Plants by applying the expertise and best practices that exist across the globe. It is intended for countries to utilize these agreed upon Guidelines to support their current policy, technology and ecosystems. Countries that have limited institutional and technical capacities, will be able to enhance their knowledge base in developing SHP plants, thereby attracting more investment in SHP projects, encouraging favourable policies and subsequently assisting in economic development at a national level. These TGs will be valuable for all countries, but especially allow for the sharing of experience and best practices between countries that have limited technical know-how.

The TGs can be used as the principles and basis for the planning, design, construction and management of SHP plants up to 30 MW.

- The Terms and Definitions in the TGs specify the professional technical terms and definitions commonly used for SHP Plants.
- The Design Guidelines provide guidelines for basic requirements, methodology and procedure in terms of site selection, hydrology, geology, project layout, configurations, energy calculations, hydraulics, electromechanical equipment selection, construction, project cost estimates, economic appraisal, financing, social and environmental assessments—with the ultimate goal of achieving the best design solutions.
- The Units Guidelines specify the technical requirements on SHP turbines, generators, hydro turbine governing systems, excitation systems, main valves as well as monitoring, control, protection and DC power supply systems.
- The Construction Guidelines can be used as the guiding technical documents for the construction of SHP projects.
- The Management Guidelines provide technical guidance for the management, operation and maintenance, technical renovation and project acceptance of SHP projects.



# Technical Guidelines for the Development of Small Hydropower Plants-Design

## Part 3: Engineering Geology

### 1 Scope

This Part of Design Guidelines clarifies the basic provisions on engineering geological investigation of an small hydropower (SHP) station, specifies the technical requirements for investigation in terms of aspects of regional geology and reservoir engineering geology and defines specific requirements for investigation technologies and methods to be applied in various stages in relation to aspects of engineering geology of the dam area, water delivery way, power plant area and natural construction materials.

### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

SHP/TG 001, *Technical guidelines for the development of small hydropower plants—Terms and definitions*.

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in SHP/TG 001 apply.

### 4 Basic provisions

#### 4.1 Basic principles

4.1.1 Engineering geological investigation should be carried out according to the design intention and engineering characteristics.

4.1.2 Before the field work, the existing geological data shall be fully collected and analysed, the site survey shall be carried out, the natural environment and working conditions on site shall be

learned, and the engineering geological investigation outline shall be prepared in combination with the engineering design plan.

4.1.3 The investigation shall be carried out in stages according to the investigation procedure, and the investigation period and workload shall be reasonable.

4.1.4 According to the characteristics of the project, the complexity of the topographic and geological conditions and the requirements of the investigation depth in each stage, a variety of investigation methods shall be comprehensively applied to reasonably arrange the investigation activities. Appropriate geological mapping, geophysical prospecting, drilling, pit exploration and indoor test shall be conducted, supplemented by adit exploration and in-situ field test depending on the situation.

4.1.5 The investigation of natural construction materials shall meet the precision and design requirements of each investigation stage.

4.1.6 The project site shall avoid as far as possible the serious seepage, large landslides and collapse, creep, dangerous rock mass, debris flow, active fault and other undesirable geological problems as well as cultural relics and ecological environment protection areas. The environmental geological problems that may arise from engineering construction shall be analysed.

## 4.2 Investigation outline

4.2.1 Before the investigation, the engineering geological investigation outline shall be prepared in accordance with the investigation assignment and in combination with the design plan.

4.2.2 The engineering geological investigation outline shall include:

- a) Project profile, investigation stage, investigation purpose and tasks as well as the main outcomes and assessment results of the investigation in the previous stage;
- b) Geology of the project site and working conditions on site;
- c) Regulations and specifications and design documents for the investigation;
- d) Investigation task requirements, arrangement principle for the investigation, working method and planned workload of the investigation;
- e) Investigation technical requirements and quality target of outcomes;
- f) Investigation schedule, resource allocation and environmental, quality and safety-ensuring measures;
- g) Contents, form and date of the engineering geological investigation outcomes to be submitted;

h) Floor plan of the exploration work.

#### 4.3 Determination of physical and mechanical parameters of the foundation soil

4.3.1 The geotechnical parameters of the bedrock may be determined by engineering geological analogy and experience-based judgment; field and laboratory tests may be performed when necessary.

4.3.2 The physical and mechanical parameters of the foundation soil shall be determined on the basis of laboratory and field tests, combined with engineering geological analogy and experience-based judgment.

### 5 Regional geology

#### 5.1 General provisions

5.1.1 The regional geological investigation shall mainly include five aspects, namely topography and geomorphology, geologic structure, regional tectonic stability and seismicity, geophysical phenomenon and hydrogeology.

5.1.2 The key emphasis of the actual investigation work shall be determined according to the specific regional geological characteristics of the project site:

- a) In the karst area, the karst development and hydrogeological conditions shall be investigated in priority.
- b) In the area with relatively strong seismic activities, the geologic structure and fault activities shall be investigated in priority.
- c) In the quaternary distribution area, the type of quaternary sediment, the development history of the river and the development situation of the terrace shall be investigated in priority.

#### 5.2 Topography and geomorphology

5.2.1 In the topography and geomorphology investigation, the topographic and geomorphic conditions shall be used reasonably according to the layout of the buildings, as well as the type, scale and construction conditions of the buildings.

5.2.2 During the topography and geomorphology investigation, the following information in the region shall be learned from satellite images and aerial photos on the basis of collecting and analysing the latest topographic data of the project site:

- a) Grade of landform;
- b) Division of geomorphic unit;
- c) Change of topographic relief;
- d) Situation of ground cutting, such as development system, form, direction, density, depth and width of the valley;
- e) Shape, height and gradient of hillside;
- f) Form, width and flatness of ridge;
- g) Width, depth and gradient of the river valley, as well as the development situation of the terrace;
- h) Steps, elevation, width, flatness, integrity degree, structure and genetic type of the terrace;
- i) Characteristics of different geomorphic units and their interrelationships.

### **5.3 Geologic structure**

**5.3.1** For geologic structure investigation, the strength and permeability of the geologic structure shall be fully considered to avoid the folds and faults.

**5.3.2** For geologic structure investigation, the geological data in the region shall be collected as far as possible. The geological data of the national small scale geological mapping and the completed or planned projects near the proposed project may be used as the basic data of geological research.

**5.3.3** After analysing and sorting the collected data, the geological structure within the proposed project area may be surveyed on site to verify its accuracy.

**5.3.4** When the geological data is not available, a geological survey shall be conducted in and around the project area to clarify the regional geologic structure.

**5.3.5** The general field work methods for regional geological survey include: surveying and preparation of the geological section, route geological survey and geological mapping, measurement of the occurrence elements, sampling of specimen and samples as well as general prospecting in mountainous region.

### **5.4 Regional tectonic stability and seismicity**

**5.4.1** For the regional tectonic stability survey, it is necessary to propose assessment opinions on

the regional structural stability, judge the possibility of the proposed hydropower project site being damaged by active fault or seismic activities in the coming one or two hundred years, the damage intensity and damage probability, and then propose the appropriate ground motion parameters for aseismic design of the project.

**5.4.2** The regional tectonic stability survey may be carried out in the following aspects:

- a) Background research of regional tectonic stability;
- b) Judgment of active fault and research of fault activity;
- c) Analysis of seismic risk and determination of site earthquake parameters;
- d) Synthetic assessment of regional tectonic stability of the project site;
- e) Monitoring of active fault and seismicity.

**5.4.3** Regional structural stability and seismic survey focus on data collection, including the collection of data concerning regional formation lithology, geologic structure, active fault, ground motion parameters or seismic basic intensity, and historical seismological data, etc. It is necessary to analyse and judge the overall stability of the regional structure of the project area, put forward ground motion parameters or the seismic basic intensity of the project area, and carry out monographic study of the active fault that might influence the project.

**5.4.4** The layout of the project should be in the favourable seismic resistance zone, avoiding the sections which might produce large-scale secondary disasters. The main structures like the dam, spillway and powerhouse should not be built on the active fault.

## **5.5 Geophysical phenomenon**

**5.5.1** For a geophysical phenomenon, the occurrence and development rules, causes, factors influencing its occurrence and development, formation conditions and mechanism, and development process and stages shall be studied to make correct assessment and formulate reasonable control measures.

**5.5.2** The possible geophysical phenomenon in the project area shall be preliminarily judged from the analysis on basic geological data such as topography and geomorphology and geologic structure. The type and development degree of various geophysical phenomena in the upstream/downstream area of the basin may be studied through field geological surveying and mapping, and the unfavorable geophysical phenomena in the reservoir area, dam site, plant site and particularly along the water diversion route shall be mainly identified, and the ground observation like drilling exploration, geophysical prospecting and pit and trough exploration may be arranged when necessary.

## 5.6 Hydrogeology

5.6.1 The adverse influence of groundwater on the construction of the project shall be found out and the control measures shall be proposed by studying the distribution and formation rules of groundwater as well as the physical property and chemical components of groundwater.

5.6.2 The hydrogeological survey mainly includes data collection, ground survey, exploration, hydrogeological testing, water chemical testing and observation; the key work shall include the lithology and burial and distribution conditions of the main aquifers, the cause, type, recharge-discharge conditions of groundwater in each aquifer as well as the distribution and variation situation of water quality and volume.

## 6 Engineering geology investigation of the reservoir area

### 6.1 General provisions

The engineering geological investigation of the reservoir area shall investigate reservoir seepage, reservoir immersion, reservoir bank (slope) stability, reservoir sedimentation and reservoir induced earthquake. In the case of an unstable slope, the underground hydrogeological conditions should also be evaluated.

### 6.2 Reservoir seepage

6.2.1 The reservoir seepage investigation shall find out topography and geomorphology, lithology, geologic structure and hydrogeological conditions of reservoir seepage, analyse the form of reservoir seepage, evaluate the possible amount of reservoir seepage and propose suggestions and measures to prevent reservoir seepage.

6.2.2 The study of reservoir seepage is mainly performed by engineering geological surveying and mapping. The following conditions that may cause the seepage shall be identified:

- a) The low thin area on one side of the reservoir area, and the adjacent valley bottom elevation is lower than the normal pool level;
- b) The area near the sharp bend of the river valley of the downstream channel of the dam is thin or the low thin area between the reservoir area and the downstream tributary of the dam;
- c) The reservoir basin is a formation with high water permeability, such as sand, sand gravel and loose deposits;
- d) The reservoir basin is composed of limestone, gypsum and other solvable rocks, and the seepage passage is formed by the karst caves, pipelines and grike;

- e) The reservoir basin and thin watershed are composed of the loose structure of sand and gravel;
- f) The columnar joints are developed in stretched manner, and the reservoir basin and thin watershed are composed of basalts with a lot of holes and caves;
- g) The reservoir basin is an anticlinal valley, which is prone to seepwater externally along the permeable stratum;
- h) The reservoir basin is a monoclinal valley, the pervious bed is lower than the normal pool level, and is exposed in the adjacent valley, with the potential of seeping to the adjacent lower valley along the inclination direction;
- i) Strongly permeable fault fracture zone and jointed intensive belt, pass through this region, or pass through the thin watershed or river bend area;
- g) The groundwater is recharged with river water in the reservoir area or the natural riverbed has already seeped to the adjacent valley, and the seepage will become worse after the reservoir filling;
- k) The groundwater level on the reservoir banks is lower than the normal pool level of the reservoir, whereas the water permeability of the rock stratum is strong.

### 6.3 Reservoir immersion

6.3.1 The reservoir immersion investigation shall find out the hydrogeological and engineering geological conditions of the area to be immersed, and the distribution and relevant characteristics of the buildings, factories and mines, villages and towns, forest and farmlands, etc. around the reservoir area. The range of immersion influence shall be determined, and prevention and control measures shall be proposed.

6.3.2 The reservoir immersion investigation shall be conducted through geological surveying and mapping and light geological exploration to investigate the relationship between rock strata, groundwater level and groundwater recharge and discharge within a certain extent above the normal pool level of the reservoir area.

6.3.3 The sections judged to be impossible to be immersed in the reservoir area shall comply with the following provisions:

- a) The sections where the reservoir banks are composed of impermeable rock-soil layers;
- b) The sections without direct hydraulic connection with the reservoir;
- c) The sections which are separated by a relatively impervious bed and the top elevation of the im-

pervious bed is higher than the normal pool level of the reservoir;

- d) The sections which are separated by the gully with constant stream and the water level of the gully is higher than the normal pool level of the reservoir.

**6.3.4** The sections judged to be unlikely to have secondary salinization in the reservoir area shall comply with the following provisions:

- a) Humid climate region with high precipitation and good runoff conditions;
- b) The degree of mineralization of the groundwater is relatively low; cohesive soil on the surface layer is relatively thin, the water permeability of the underlying aquifer is relatively high and the drainage condition is relatively good;
- c) The drainage facilities are well-channelled.

#### **6.4 Reservoir banks/rim slope stability**

**6.4.1** The reservoir bank stability investigation shall find out the engineering geological conditions with potential instability factors for the reservoir banks, such as a landslide and collapse, evaluate their influences, ascertain the engineering geological conditions of the soil bank slope and predict the extent of bank collapse, and propose suggestions on control measures.

**6.4.2** The form, formation lithology and physico-geological function of the reservoir banks shall be learned by engineering geological surveying and mapping and general prospecting means, the stability of the reservoir bank in the unimpoundment state shall be judged, and the possibility and extent of bank slumps of the soil bank slope induced by waves and scouring under the effect of reservoir water and waves shall be studied and predicted.

**6.4.3** The geological and topographical conditions of reservoir rock banks shall be ascertained, such as the slope shape, drainage conditions, material composition, rock mass structure and particularly the development and combination features of weak intercalations in the rock mass. The possibility of landslide and rockfall for reservoir rock banks shall be analysed and predicted in combination with the hydrology, meteorology, reservoir water depth and dispatching mode of the reservoir.

**6.4.4** In order to ascertain the type, nature, distribution range, scale, controlling structural surface characteristics and underground hydrogeological conditions of the unstable slope near the dam and reservoir area, Test Pits and Trenches, geophysical prospecting, drilling and other exploration works shall be arranged. The slope stability and the extent and scale of possible deformation and failure under different reservoir water level conditions shall be predicted and evaluated. The possible effects of deformation and instability shall be assessed.



## 6.5 Reservoir sedimentation

6.5.1 The reservoir sedimentation investigation shall include the scour and erosion situation of the upstream rivers and gully of the reservoir and the source of the sediment runoff in the reservoir area. The reservoir sedimentation problems shall be assessed and suggestions on control measures shall be proposed.

6.5.2 The key work of the reservoir sedimentation assessment is to find out the source of the sediment runoff in the reservoir area. The engineering geological conditions of reservoir area shall be learned through engineering geological surveying and mapping, to analyse and study the genetic type and material composition of the rock masses in the sections where sediment runoff originates, the scouring and cutting strength of the water flow, the slope characteristics, stability degree and damage forms, distribution and activity of the debris flow as well as the situation of solid substances being carried by the water flow.

## 7 Engineering geological investigation of the dam area

### 7.1 General provisions

The engineering geological investigation in the dam area should be carried out according to the accuracy requirements of two different design stages of the pre-feasibility study and feasibility study, mainly including the basic geological conditions, such as the topography, stratum lithology, geological structure, and the physical geology, to evaluate the main engineering geological problems in the dam area.

### 7.2 Pre-feasibility study stage

7.2.1 In the pre-feasibility study stage, the engineering geological conditions and the main engineering geological problems of the site selection scheme shall be preliminarily analyzed, to demonstrate the feasibility of hydropower station construction from the perspective of engineering geology. The following contents shall be included in the investigation:

- a) River morphology and the valley's topographic features of the river reach where the dam site is located;
- b) Stratum lithology, bedrock types, distribution of weak strata, the cause, structure, basic property, composition material and distribution situation of Quaternary sediments in the dam area;
- c) Main geologic structure of the dam area, particularly the development position, type, occurrence, scale and composition material of the large-scale fracture zone;
- d) Weathering, unloading, landslides, collapse, dangerous rock and other physical and geological

phenomena of the rock mass at the dam site and near the dam area;

- e) Distribution of strongly pervious bed, karst and fossil river course in the dam area.

7.2.2 In the pre-feasibility study stage, the engineering geological investigation mainly focuses on data collection and geological surveying and mapping. The following requirements shall be met in the selection of working methods and the arrangement of investigation work:

- a) Geological surveying and mapping: When the engineering geological condition is relatively simple, the geologic map of the reservoir area may be adopted, while the engineering geological map of the dam area may not be drawn separately; when the engineering geological condition is relatively complex, it is recommended to draw a 1 : 2 000 to 1 : 1 000 scale engineering geological map of the dam area.
- b) Arrangement of the investigation work: Main for exploring the mining and trenching. Usually detailed prospecting work is not arranged; when the engineering geological condition is relatively complex, a small amount of geophysical prospecting and drilling exploration may be arranged which are usually applied for the axis of the retaining dam.
- c) The geophysical prospecting profile shall be arranged according to the geological and topographical conditions of the dam area combined with the exploration profile.
- d) The drilling should be arranged on the axis of the retaining dam, the spacing between drilled holes should not be more than 100 m and the drilling should be arranged on the riverbed and the dam shoulders of both banks.
- e) For a rock-based dam site, the depth of drilling in the riverbed should not be less than the dam height. The drilling in the dam shoulders on both banks should be arranged on the elevation above the dam crest, and the drilling shall go into the relative confining bed. The depth of drilling in the karst area shall not be less than 10 m below the groundwater level.
- f) For a soil-based dam site, the drilling depth should not be less than the dam height; if the soft layer or highly pervious bed is distributed in the dam foundation, the drilling depth shall be 5 m to 10 m in the relative confining bed of the solid soil layer or base rock.
- g) Hydrological testing shall be done for all boreholes, water pressure testing should be done for bedrock, water injection testing or pumping testing should be done for broken bedrock that cannot be tested by water pressure and overburden.
- h) Sampling, standard penetration tests or cone dynamic penetration tests may be conducted for the overburden by the properties of the layer.
- i) The geological parameters may be determined by engineering geological analogy and experience-

based judgment. Site and indoor testing may be conducted when necessary.

### 7.3 Feasibility study stage

7.3.1 In the feasibility study stage, the engineering geological investigation in the dam area mainly involves the investigation of basic geological conditions such as the topography and geomorphology, stratum lithology, geologic structure and hydrogeology and physical geological phenomena, as well as the major engineering geological problems in each dam area, and the preliminary evaluation of the major engineering geological problems. Through comparison and selection of dam site schemes, representative dam site schemes are recommended, and the selected dam site schemes are geologically certified. The following contents shall be included in this stage:

- a) Preliminary identification of the topographic and geomorphic features of each selected dam site, especially gull, bealock, past river channels and deep groove of riverbed;
- b) Preliminary identification of the stratum lithology of each selected dam site, especially the distribution of weak rock, karst, expansive rock and other bad rock or interlayer; preliminarily identification of the distribution, cause, basic property and composition of Quaternary sediments, especially the distribution of soft soil, expansive soil, dispersed soil, silty sand, past channel and collapsible loess
- c) Preliminary identification of the development location, type, occurrence, scale and composition of the major faults and fractured zones in the selected dam site, especially the investigation of along-river faults and low angle faults. Cracks shall be measured by the left bank, right bank and riverbed.
- d) Preliminary identification of the physical and geological phenomena in the selected dam sites, such as the weathering degree of the rock mass, the unloading depth, the size and distribution of a landslide, collapse, dumping body, dangerous rock and potential unstable body;
- e) Preliminary identification of the permeability of the rock and soil layers and the burial conditions of the relative water-resisting layers, hydrogeological conditions, such as the recharge and discharge relationship between surface water and groundwater, and the aggressiveness of the concrete in each selected dam area. The investigation of ancient river channels in special areas shall also be paid attention to;
- f) Preliminary identification of the development and distribution of karst, investigation of the distribution, scale and filling of the main cave and seepage channel; initially investigate the storage of groundwater, water dynamic characteristics and supply relationships. Preliminary identification of the characteristics of the relatively water-resisting strata, preliminary analysis of the possible leakage area and type, and offering a suggestion for the treatment scheme.
- g) The physical and mechanical parameters of all the kinds of rock and soil shall be proposed. Classi-

fy the dam bedrock by engineering geology. For details, see Appendix A.

7.3.2 When selecting the working methods and arranging the investigation work, the following requirements shall be met:

- a) Geological surveying and mapping; 1 : 2 000 to 1 : 500 scale engineering geological map for the dam area shall be drawn.
- b) Layout of the exploration work; a small amount of geophysical exploration and drilling work shall be adopted. Each comparative dam area shall have at least one representative exploration section line in conjunction with the layout the building:
  - 1) The exploration line for an earth and rockfill dam shall be arranged along the seepage control line or axis of the dam.
  - 2) The exploration line for concrete dams like gravity dams and arch dams shall be arranged along the axis of the dam.
  - 3) The exploration line for general barrages shall be arranged along the axis. The auxiliary exploration section line may be determined according to the position and demand of the civil structures.
- c) The geophysical prospecting and pit slot exploration shall be arranged according to the geological and topographical conditions of the dam area. The drill holes are usually arranged on the position of the main exploration line, in the riverbed and the dam shoulders on both banks. The spacing between drill holes should not be more than 50 m:
  - 1) For a rock-based dam site, the depth of drilling in the riverbed should not be less than the dam height. The drilling in the dam shoulders on both banks should be arranged on the elevation above the dam crest, and the drilling shall go less than 10 m into the relative confining bed. The depth of drilling in the karst area shall not be less than 10 m below the groundwater level.
  - 2) For a soil-based dam site, the drilling depth should not be less than the dam height; if the soft layer or highly-pervious bed is distributed in the dam foundation, the drilling depth shall be 5 m to 10 m into the relative confining bed of the solid soil layer or base rock.
  - 3) The drilling in the karst area shall go into the relative confining bed or the weakly dissoluble rock strata; the spacing between the drilled holes should be penetrated with seismic waves and tested with the tomographic technique.
- d) For concrete dams, particularly the arch concrete dam, adit control should be provided for the dam shoulders on both banks; the adit shall be deep enough to expose the intensely weathered

zone and the unloading belt of the rock mass to ascertain the weak intercalated layer and other adverse structural surfaces.

- e) The following tests shall be carried out:
  - 1) The borehole shall be hydrologically tested in sections.
  - 2) The bedrock should be subjected to the water pressure test.
  - 3) The fractured bedrock which cannot be subjected to the water pressure test should be subjected to the water injection test.
  - 4) The Quaternary overburden should be subjected to the water injection test or the pumping test.
  - 5) During the drilling process in the karst area, the groundwater level should be observed, and tracer tests should be carried out if necessary.
- f) At least a group of surface water and a group of groundwater samples shall be taken for water quality analysis to assess its aggressiveness to the concrete and steel structures. For details, see Appendix B.
- g) When the overburden is needed as the dam foundation, the sampling, standard penetration test or conical dynamic penetration tests shall be carried out according to the nature of the soil layer; the effective groups of sampling in each soil layer should not be less than 6.
- h) Rock base shall be determined by engineering geological analogy and experience-based judgment, combined with the field and laboratory tests. The physical and mechanics parameters of the earth base shall be determined on the basis of the field and laboratory test results, combined with the engineering geological analogy and experience-based judgment.

## **8 Engineering geological investigation of the water conductor project**

### **8.1 General provisions**

The engineering geological investigation of the water conductor project should be carried out according to the precision requirements of two different design stages of pre-feasibility study and feasibility study. The engineering geological and hydrogeological conditions along the water conductor line and the building areas should be investigated and studied, and the main engineering geological problems that may be encountered along the line should be evaluated.

## 8.2 Pre-feasibility study stage

8.2.1 In the pre-feasibility study stage, the engineering geological conditions and the main engineering geological problems in the comparison schemes of the water conductor line shall be investigated, with the following contents as the focus:

- a) The topographic and geomorphological features and physical and geological phenomena in the water conductor line area, especially the distribution of landslides, collapses and debris flows;
- b) Formation lithology, segmentation of the rock and soil layers and distribution of special rock and soil layers in the line area;
- c) The main geologic structure of the line area, particularly the development position, type, occurrence, scale and composition of the fracture zone;
- d) Hydrogeological conditions in the line area, particularly the karst area;
- e) Engineering geological conditions at each opening of tunnels as well as the adverse geologic phenomena affecting the stability of the tunnel.

8.2.2 The following requirements shall be met in the selection of working methods and the investigation work arrangement:

- a) The engineering geological investigation is performed mainly to collect regional geological data and to survey and map for the geology; geophysical prospecting and drilling exploration may be arranged in the important sections. The scope of the geological surveying and mapping should include 1 km on both sides of the axis. The measuring scale should be 1 : 50 000 to 1 : 10 000.
- b) For the channels, the surveying and mapping for geology shall be mainly used, and the geophysical prospecting profile should be arranged, along the centreline if necessary; in the sections with complex engineering geological conditions, the auxiliary survey line shall be arranged vertical to the axis; the geophysical prospecting methods shall be selected according to the prospecting purpose and physical characteristics of the rock and soil layers.
- c) For the tunnels, the surveying and mapping for geology is mainly used along the centreline. The drilling should be arranged in the entrance/exit of the tunnel, the shallowly buried section beside the hill, the ditch-passing section and other sections with complex engineering geological conditions; drilling may be set if necessary and the drilling depth shall be less than 10 m below the tunnel bottom elevation.
- d) Pump-in (injection) tests shall be performed for the drilled holes; pumping tests shall be carried out for the confined water distribution areas.

- e) The geological parameters may be determined by engineering geological analogy and experience-based judgment; field and laboratory tests may be performed when necessary.

### 8.3 Feasibility study stage

8.3.1 The engineering geological investigation for the water conductor project in the feasibility study stage mainly include the investigation for the topography and geomorphology, formation lithology, geologic structure and hydrological geology, as well as the main engineering geological problems and preliminary evaluation of its impact on various types of water conductor structures and the geological certification shall be conducted for selection of suitable water conductor line scheme. The following contents shall be initially investigated:

- a) The topographic and geomorphological features and physical and geological phenomena of the water conductor line area, especially the distribution of landslides, collapses and debris flows;
- b) Formation lithology of the route area, segmentation of the rock and soil layers and whether special rock and soil layers are distributed in this area;
- c) The main geologic structure of the route area, particularly the development position, type, occurrence, scale and composition materials of the fracture zone;
- d) Hydrogeological conditions in the route area, particularly in the karst area;
- e) Engineering geological conditions at the openings of tunnels as well as the adverse geologic phenomena affecting the stability of the tunnel;
- f) If the tunnel runs through the coal-bearing stratum, the oil shale and bituminous stratum, the harmful gases shall be studied; radioactive elements shall be tested and studied in large intrusive masses;
- g) The physical and mechanical parameters of various rock and soil bodies are proposed; the tunnel surrounding rocks shall be preliminarily classified. For details, see Appendix B.

8.3.2 The following requirements shall be met in the selection of working methods and the arrangement of investigation:

- a) Focusing on data collection and geological surveying and mapping. The scope of the geological surveying and mapping should include 1 km area on both sides of the axis. The measuring scale for the water conductor project should be 1 : 10 000 to 1 : 5 000; specific geological surveying and mapping shall be performed for the channel section adjacent to the hill as well as the high fill, deep excavation and the channel with complex engineering geological conditions. The mapping scale should be 1 : 2 000 to 1 : 1 000. The geological surveying and mapping of the entrance/exit of the tunnel, the shallow-buried section along the hill, the gully section and other

sections with complex engineering geological conditions shall be carried out with the scale of 1 : 2 000 to 1 : 1 000.

- b) The geophysical prospecting profile shall be arranged along the centreline of the channel; in the sections with complex engineering geological conditions, the auxiliary survey line shall be arranged vertical to the axis; the geophysical prospecting methods shall be selected according to the prospecting purpose and physical characteristics of the rock and soil layers.
- c) On the basis of the geophysical prospecting profile, the exploration profile should be arranged along the centreline of the channel, and the exploration points shall be arranged in the sections across the rivers and ditches and sections with complex engineering geological conditions, and the spacing should not be greater than 1 000 m; the prospecting should be realized mainly by Test Pits and Trenches, and drilling exploration; the drilling exploration depth should be 10 m below the design floor elevation.
- d) Geological surveying and mapping should be carried out along the tunnel. Geophysical profiles should be arranged along the central line when necessary to explore the thickness of the overburden, weathering degree of the rock mass and karst development of the tunnel section.
- e) The drilling should be arranged in the entrance/exit of the tunnel, shallow-buried section along the hill, gully section and other sections with complex engineering geological conditions; the drilling depth shall be 10 m below the tunnel bottom elevation.
- f) Pump-in (injection) tests shall be performed for drilled holes; pumping tests shall be carried out for the confined water distribution areas.
- g) The geological parameters shall be determined by the field and laboratory tests, combined with engineering geological analogy and experience-based judgment.

## 9 Engineering geological investigation of the power plant area

### 9.1 General provisions

The engineering geological investigation of the power plant area should be carried out according to the accuracy requirements of the pre-feasibility study and the feasibility study. The main engineering geological problems of the power plant area should be evaluated by investigating and studying the engineering geological conditions of the power plant, penstock and slope behind the plant.

### 9.2 Pre-feasibility study stage

9.2.1 In the pre-feasibility study stage, the engineering geological conditions and the main engineering geological problems in the power plant area should be investigated, with the focus on the follow-



ing contents:

- a) Morphological characteristics of the topography and geomorphology of the plant area;
- b) Formation lithology, as well as the cause, composition material and distribution of the overburden of the plant area;
- c) Main geologic structure of the plant area, the development position, type, occurrence, scale and composition materials of the fracture zone;
- d) Physical and geological phenomena such as the weathering degree of the rock mass, unloading, landslide, collapse and debris flow in the plant area;
- e) Slope stability of the powerhouse.

**9.2.2** The engineering geological investigation mainly involves collecting regional geological data and geological surveying and mapping. A small amount of geophysical prospecting and drilling exploration may be performed in the plant area with complex engineering geological conditions.

- a) When the engineering geological condition is relatively simple and the project is close to the reservoir area, the geologic surveying and mapping may be combined with the geologic map of the reservoir area, and the engineering geological map of the plant area may not be necessary; when the engineering geological condition is relatively complex, a 1 : 2 000 to 1 : 1 000 scale engineering geological map should be drawn.
- b) When the engineering geological condition is relatively complex, a small amount of geophysical prospecting and drilling exploration may be arranged in the plant area and the slope behind the plant.
- c) The geophysical prospecting profile should be arranged along the centreline of the penstock for the purpose of investigating the overburden thickness, weathering degree of the rock mass and unloading condition in the sections of the penstock.
- d) The spacing between drill holes shall be determined according to the engineering geological conditions of the plant area, and the drilling depth should be 10 m to 20 m below the foundation surface elevation.
- e) The geological parameters may be determined by the engineering geological analogy and experience-based judgment; field and laboratory tests may be performed if necessary.

### **9.3 Feasibility study stage**

**9.3.1** In the stage of the feasibility study, the engineering geological investigation of the power

plant area mainly carries out the investigation of basic geological conditions such as the topography, stratum lithology, geological structure, hydrogeology and major engineering geological problems of each selected plant area. Through comparison and selection of different selected plant area schemes, the representative plant area should be recommended. The following contents in each selected plant area need to be preliminarily ascertained:

- a) Morphological characteristics of the topography and geomorphology;
- b) Formation lithology, as well as cause, composition material and distribution;
- c) Main geologic structure, the development position, type, occurrence, scale and composition materials of fracture zone;
- d) Physical and geological phenomena such as weathering degree of rock mass, unloading, landslide, collapse and debris flow;
- e) The stability of the slope at the back of the powerhouse;
- f) The hydrogeological conditions, focusing on the evaluation of the plant foundation pit seepage characteristics, forebay leakage and seepage deformation, surface water and groundwater corrosive to the concrete and steel structures, etc.

9.3.2 The following requirements shall be met in the selection of working methods and the arrangement of investigation:

- a) In the plant area, the engineering surveying and mapping may be performed in combination with the engineering geological map of the dam area. The engineering geological map of the plant area shall be drawn separately if it is not included in the dam area. The measuring scale for the geological surveying and mapping should be 1 : 2 000 to 1 : 1 000; the mapping scope shall include the alternative schemes of the surge shaft, penstock, powerhouse, switchyard and other structures.
- b) The investigation work is carried out mainly by geophysical prospecting and drilling exploration, and is usually arranged in the surge shaft, the slopes at the back of the powerhouse (including the forebay and penstock), the powerhouse and the switchyard, combined with exploring, mining and trenching.
- c) The exploration profile shall be arranged in combination with the axis of the civil structures; the exploration profile shall also be arranged on the slopes which might influence the safety of civil structures.
- d) The drilling in the places such as the surge shaft, forebay, penstock, powerhouse and switchyard shall be 5 m to 10 m below the foundation surface; when the foundation is located on the o-

verburden, the drilling depth shall be determined according to the distribution of the bearing stratum.

- e) Pump-in (injection) tests shall be performed for the drilling in the surge shaft, forebay and powerhouse; when the foundation is the main aquifer of the Quaternary, the drilling pumping test should be carried out.
- f) At least one group of surface water samples and one group of groundwater samples shall be taken for water quality analysis to assess its corrosiveness to the concrete and steel structures.
- g) Sampling, standard penetration test or conical dynamic penetration test shall be carried out according to different soil properties when the foundation of the forebay, penstock, powerhouse and switchyard is the overburden, and the number of effective sampling groups in each soil layer should not be less than 6.
- h) The geological parameters shall be determined according to the field and laboratory tests, combined with the engineering geological analogy and experience-based judgment.

## 10 Geological investigation of natural construction materials

### 10.1 General provisions

The investigation of natural construction materials shall be carried out according to the requirements at different design stages and the types and quantities of construction materials; when natural construction materials affect the basic dam type, a detailed investigation shall be carried out in the engineering geological investigation at the feasibility study stage; comprehensive utilization of the engineering excavation materials shall be fully considered in the selection of material sources; when outsourcing is adopted, the quality of the purchased natural construction materials shall be reviewed and their supply capacity shall be evaluated.

### 10.2 Pre-feasibility study stage

10.2.1 In the pre-feasibility study stage, a general survey for the natural construction materials required by the project shall be carried out.

10.2.2 The geological investigation around the project area shall be carried out on the basis of collecting and analysing the relevant data in the region. The safety and environmental factors shall be fully considered in the selection of natural construction materials field; its quality and reserves may be judged preliminarily according to the engineering geological analogy and experience-based judgment to meet the project needs.

### 10.3 Feasibility study stage

10.3.1 In the feasibility study stage, natural construction materials such as rock, sand and gravel, and the soil materials for project construction shall be investigated. The investigation shall be performed from near to far, and the qualitative and quantitative research of natural construction materials shall be carried out. The safety and environmental factors of the planned material field shall be fully considered, and the impact of natural construction material mining on the environment shall be analysed.

10.3.2 The investigation shall focus on data collection, geological survey and geological mapping, and pit, trough and drilling surveys should be arranged when necessary.

10.3.3 The investigated reserves of various natural construction materials shall be twice as much as the design requirements.

10.3.4 The selected block stones shall be judged on the basis of the origin. If the strength and quality of the rocks highly exceed the design requirements, the physico-mechanical indices of the rocks may be determined by the engineering geological analogy and experience-based judgment to estimate the reserves.

10.3.5 The quarry area with a strongly weathered overburden and rocks shall be investigated; the investigation holes should be arranged in latticed form, and the spacing should be less than 100 m; the hole depth shall be 5 m to 10 m below the elevation of the bottom to be excavated.

10.3.6 Rock samples shall be taken from the quarry area to measure the density and compressive strength of the rocks. If the selected block stones are used as the artificial aggregates of the concrete, the water absorption, soundness, crushing value and alkali activity of the rocks shall be tested.

10.3.7 The Test Pits should be arranged for the sand-gravel quarry area according to the following requirements:

- a) With regard to the quarry area with widely distributed and stable sand-gravel and a thick productive layer, the spacing between Test Pits shall be 100 m to 200 m.
- b) With regard to the quarry area where sand-gravel is distributed in strip form and the productive layers vary remarkably, the spacing between Test Pits shall be 50 m to 100 m.
- c) At least three Test Pits shall be arranged in every quarry area, and the well depth shall be 1 m below the maximum excavation depth.

10.3.8 The sand-gravel quarry area shall be sampled for screening test to calculate the reserves of sand-gravel materials at all levels. The organic matter and sediment percentage of sand material shall

be measured.

**10.3.9** The exploratory points of the soil material field should be arranged according to the following requirements:

- a) With regard to the soil material field with a large area, flat terrain, a thick productive layer and a single soil layer, the spacing between exploratory points shall be 100 m to 200 m.
- b) With regard to the soil material field with a small area, undulating terrain, a highly variable thickness of the productive layer and complex soil layer structure, the spacing between exploratory points shall be 50 m to 100 m.
- c) At least three Test Pits shall be arranged in each material field, and the well depth shall be 0.5 m to 1 m below the maximum excavation depth.

**10.3.10** The soil material field shall be sampled for routine test and compaction test; the routine test mainly includes the natural water content, density, specific gravity, liquid limit, plastic limit, particle analysis, organic content and water-soluble salt content.

**10.3.11** In order to learn about the compactibility of the soil material, the compaction tests shall be carried out to determine the relationship between the density and water content of the soil material; for some expansive soils, the expansibility, chemical components and clay minerals should also be measured.

**10.3.12** The investigation of the impact of mining conditions and environmental geology should be conducted, mainly including the distance between the quarry area and the proposed project area, the existing access road, groundwater level and water yield property of the quarry area. The damage to vegetation the impact on the geological environment after mining shall be forecasted, and suggestions on treatment and restoration shall be presented when necessary.

**Appendix A**  
**(Informative)**

**Engineering geologic classification of the dam foundation rock mass**

Engineering geologic classification of the dam foundation rock mass of SHP plants shall meet the regulations in Table A.1.

**Table A.1 Engineering geologic classification of the dam foundation rock mass**

Type	Rock mass characteristics	Rock mass engineering property evaluation	Rock mass main characteristic value
A hard rock ( $R_b > 60$ MPa)			
I	<p><math>A_I</math> : The rock mass is in a monolithic or blocky structure, and in the huge-thick formation or thick-rock formation. The structural surfaces are poorly developed or do not develop and are mainly closed with poor extension. Differences in rock mass mechanical properties in different directions are not obvious.</p>	<p>The rock mass is complete and has high strength, skid resistance and resistance to deformation, so no special foundation treatment not required. This belongs to the high-quality concrete dam foundation.</p>	<p><math>R_b &gt; 90</math> MPa  <math>V_p &gt; 5\ 000</math> m/s  <math>RQD &gt; 85\%</math>  <math>K_v &gt; 0.85</math></p>
II	<p><math>A_{II}</math> : The rock mass is in a blocky or sub-blocky structure, and in the thick-rock formation. The structural surfaces are moderately developed, and weak structural surfaces are not controllable ones and partially distributed. There is no large-scale wedge body or pyramid body that affects the stability of the dam foundation or dam shoulder.</p>	<p>The rock mass is complete and high in strength, skid resistance and resistance to deformation and the weak structural surfaces do not control the stability of the rock mass, so no great amount of work is needed for special foundation treatment. This belongs to the high-quality concrete dam foundation.</p>	<p><math>R_b &gt; 60</math> MPa  <math>V_p &gt; 4\ 500</math> m/s  <math>RQD &gt; 70\%</math>  <math>K_v &gt; 0.75</math></p>
III	<p><math>A_{III1}</math> : The rock mass is in sub-blocky structure, and in the medium-or thin-rock formation. The structural surfaces are moderately developed and the weak structural surfaces with low-angle dips and high dip angles (dam abutment) are distributed in the rock mass. There is a wedge body or pyramid body that affects the stability of the partial dam foundation or dam shoulder.</p>	<p>The rock mass is relatively complete, poor in partial completeness, and high in strength. The skid resistance and resistance to deformation are controlled to some extent by the structural surfaces. Partial special foundation treatment is required to treat the rock mass deformation and stability.</p>	<p><math>R_b &gt; 60</math> MPa  <math>V_p = 4\ 000 \sim 4\ 500</math> m/s  <math>RQD = 40\% \sim 70\%</math>  <math>K_v = 0.55 \sim 0.75</math></p>

Table A.1 (continued)

Type	Rock mass characteristics	Rock mass engineering property evaluation	Rock mass main characteristic value
A hard rock ( $R_b > 60$ MPa)			
III	$A_{III2}$ : The rock mass is in an intercalated or inlaid structure, and in the medium-or thick-rock formation. The formation surface is in a siliceous or calcite cementation thin stratified structure. The structural surfaces are developed and mostly closed with poor extension. Interlocking between the rocks is good.	The rock mass is high in strength and lacks partial completeness. The skid resistance and resistance to deformation are controlled by the degree of development of the structural surfaces, the interlocking between rocks, and the overall strength characteristics of the rock mass. Foundation treatment is required to improve the rock mass completeness.	$R_b > 60$ MPa $V_p = 3\ 000 \sim 4\ 500$ m/s $RQD = 20\% \sim 40\%$ $K_v = 0.35 \sim 0.55$
IV	$A_{IV1}$ : The rock mass is in a intercalated or thin stratified structure. The interlayer bonding is poor, and the structural surfaces are relatively well developed. The structural surfaces and large wedge body or pyramid body affect the stability of the dam foundation or dam shoulder.	The rock mass lacks completeness. The skid resistance and resistance to deformation are controlled by the structural surfaces. Whether it can be used for the high concrete dam depends on treatment difficulty and effect.	$R_b > 60$ MPa $V_p = 2\ 500 \sim 3\ 500$ m/s $RQD = 20\% \sim 40\%$ $K_v = 0.35 \sim 0.55$
	$A_{IV2}$ : The rock mass is in inlaid or cataclastic structure. The structural surfaces are well developed and are mainly open or with debris and mud. Interlocking between rocks is poor.	The rock mass is broken and lacks skid resistance and resistance to deformation. This rock mass cannot be used for high concrete dams. When this rock mass is used in a partial dam foundation, special treatment is required.	$R_b > 60$ MPa $V_p < 2\ 500$ m/s $RQD < 20\%$ $K_v < 0.35$
V	V: The rock mass is in a loose structure, consists of rocks with mud or surrounded by mud, and has characteristics of loose continuous medium.	The rock mass is broken and cannot be used for high concrete dams. When this rock mass is used in a partial dam foundation, special treatment is required.	

Table A.1 (continued)

Type	Rock mass characteristics	Rock mass engineering property evaluation	Rock mass main characteristic value
B medium-hard rocks (Rb = 30 MPa~60 MPa)			
I	—	—	—
II	B <sub>II1</sub> : The rock mass structure of B <sub>II</sub> is similar to that of A <sub>I</sub> .	The rock mass is complete, has high strength, and relatively high skid resistance and resistance to deformation, so the not much work for special foundation treatment is needed. This belongs to a good concrete dam foundation.	Rb = 40~60 MPa Vp = 4 000~4 500 m/s RQD > 70% Kv > 0.75
III	B <sub>III1</sub> : The rock mass structure of B <sub>III</sub> is similar to that of A <sub>II</sub> .	The rock mass is relatively complete and has suitable strength. The skid resistance and resistance to deformation are controlled to some extent by the structural surfaces and rock strength. Partial special foundation treatment is required to treat the structural surfaces that affect the rock mass deformation and stability.	Rb = 40~60 MPa Vp = 3 500~4 000 m/s RQD = 40%~70% Kv = 0.55~0.75
	B <sub>III2</sub> : The rock mass is in a sub-blocky structure, in the medium-or thick-rock formation and in the siliceous or calcite cementation thin stratified structure. The structural surfaces are moderately developed and are mainly closed. Interlocking between the rocks is poor. There are rare penetrating structural surfaces.	The rock mass is relatively complete and lacks partial completeness. The skid resistance and resistance to deformation are controlled by the structural surfaces and rock strength.	Rb = 40~60 MPa Vp = 3 000~3 500 m/s RQD = 20%~40% Kv = 0.35~0.55
IV	B <sub>IV1</sub> : The rock mass is in the intercalated or thin stratified structure. The interlayer bonding is poor. There are weak structural surfaces and a large wedge body or pyramid body that affect the stability of the dam foundation or dam shoulder.	Same as that of A <sub>IV1</sub> .	Rb = 30~60 MPa Vp = 2 000~3 000 m/s RQD = 20%~40% Kv < 0.35
	B <sub>IV2</sub> : The rock mass is broken or has a thin stratified structure. The structural surfaces are well developed and mainly opened. Interlocking between the rocks is poor.	Same as that of A <sub>IV2</sub> .	Rb = 30~60 MPa Vp < 2 000 m/s RQD < 20% Kv < 0.35



Table A.1 (continued)

Type	Rock mass characteristics	Rock mass engineering property evaluation	Rock mass main characteristic value
B medium-hard rocks ( $R_b = 30 \text{ MPa} \sim 60 \text{ MPa}$ )			
V	Same as that of Av.	Same as that of Av.	—
C Soft rock ( $R_b < 30 \text{ MPa}$ )			
I	—	—	—
II	—	—	—
III	$C_{III}$ : With the rock strength of 15 MPa to 30 MPa, the rock mass is in the monolithic or in the huge-thick formation. The structural surfaces are not or are only moderately developed. Differences of rock mass mechanical properties in different directions are not obvious.	The rock mass is complete and the skid resistance and resistance to deformation are controlled by the rock strength.	$R_b < 30 \text{ MPa}$ $V_p = 2\,500 \sim 3\,500 \text{ m/s}$ $RQD > 50\%$ $K_v > 0.55$
IV	$C_{IV}$ : When the rock strength is greater than 15 MPa, the structural surfaces are relatively well developed; if the rock strength is less than 15 MPa, the structural surfaces are moderately developed.	The rock mass is complete and lack strength, skid resistance and resistance to deformation. This rock mass cannot be used for high concrete dams. When this rock mass is used in partial dam foundation, special treatment is required.	$R_b < 30 \text{ MPa}$ $V_p < 2\,500 \text{ m/s}$ $RQD < 50\%$ $K_v < 0.55$
V	Same as that of Av.	Same as that of Av.	—

**Appendix B**  
**( Informative )**  
**Surrounding rock engineering geologic classification**

A.1 Surrounding rock engineering geologic classification of SHP plants shall meet the regulations in Table B.1.

**Table B.1 Surrounding rock engineering geologic classification**

Surrounding rock type	Surrounding rock stability	Main engineering geological characteristics of surrounding rocks	Unlined tunnel self-stabilization and deformation	Support type
I	Stable	Hard rocks are fresh and weakly weathered. The bedded rocks are in the huge-thick formation and the different rock formations are firmly bonded. The rock mass is wholly in blocky structure with high strength and is complete. Therefore, joint fissures do not develop and there is no unfavourable structural surface combination or ground water emergence. The rock formation is well formed. The rocks are stable over the long term with occasional falling blocks.	Rock burst may occur in deep buried or high stress areas.	Not supported or random anchor rod
II	Basically stable	Hard rocks are weakly weathered and in blocky structure, or medium-or thick-rock formation. The rock mass is complete with high strength and structural surfaces. Different rock formations are well bonded. There is no unstable structural surface combination or soft rock formation. The ground water moves slightly and the intersection angle between the tunnel line and the main structural surface is greater than 30°.	Basically stable. The surrounding rocks can maintain stable for a long time overall with falling blocks partially. Rocks in the flat rock formation or fracture top may collapse partially.	Generally not supported. Some are reinforced with pneumatically placed concrete combined with the anchor rod. The vault in the flat rock formation shall be supported timely.
		Medium-rocks are weakly weathered and in blocky structure. The rock mass is in overall structure or thick rock formation and is complete. With the joint fissure not developed, there is no unfavourable structural surface combination or soft rock formation. The ground water moves slightly and the intersection angle between the tunnel line and the main structural surface is more than 45°. The rock formation inclination is greater than 45°.		

Table B.1 ( continued )

Surrounding rock type	Surrounding rock stability	Main engineering geological characteristics of surrounding rocks	Unlined tunnel self-stabilization and deformation	Support type
III	Partially poor stability	<p>Hard rocks are in a thin stratified structure and weakly weathered and moderately weathered. There is no soft rock formation. Seriously affected by the rock frame, the joint fissure develops. The rock mass lacks completeness and has intercalated mud or mud film on the broken surface. Different rock formations are not well bonded. The ground water moves slightly and the intersection angle between the tunnel line and the main structural surface is greater than 45°. The rock formation inclination is greater than 30°.</p>	<p>The surrounding rock stability is controlled by the weak structural surface. Small and medium-sized collapses may occur. Unlined tunnels can be stable over a short term. Complete relatively soft rocks have high stability but insufficient strength. Therefore, plastic deformation or small and medium-sized collapses may partially occur. Short-term stability can be maintained.</p>	<p>Combined bolting and shotcrete or shotcrete-bolting mesh; vault system anchor rod</p>
		<p>Hard rocks are mainly intercalated with medium hard rocks, soft rocks, weakly weathered rocks, or many moderately weathered rocks. Affected by the rock frame, the joint fissure develops. There is a penetrating weak structural surface or partially unfavourable combination. The rock mass lacks completeness and shows as a blocky structure. The ground water moves medially. There are a lot of drips or streamline flows along the fracture or weak structural surface. The intersection angle between the tunnel line and the main structural surface is greater than 45°.</p>		
		<p>Medium hard rocks are weakly weathered and intercalated with moderate weathered igneous rocks, metamorphic rocks, and sedimentary rocks in the medium rock formation. The rock mass lacks completeness, so the joint fissure develops and there is penetrating weak structural surface. The ground water moves medially. There are a lot of drips or streamline flows along the fracture or weak structural surface. The intersection angle between the tunnel line and the main structural surface is greater than 30°.</p>		
<p>Relatively soft rocks, with even lithology, are weakly weathered and are in a huge-thick formation. The rock mass is complete, and the joint fissure does not develop. There is no filling material in the close joint or control weak structural surface. The rock mass has low resistance to weather and its strength quickly declines after being exposed to the atmosphere and water. The ground water moves slightly. The intersection angle between the tunnel line and the rock formation is greater than 30°.</p>				

Table B.1 (continued)

Surrounding rock type	Surrounding rock stability	Main engineering geological characteristics of surrounding rocks	Unlined tunnel self-stabilization and deformation	Support type
IV	Stable	<p>Hard rocks are interbedded with soft rocks, so weakly weathered rocks are interbedded with strongly weathered rocks. With the joint fissure developed, the rock mass is relatively broken. The rock formation surface easily constitutes unstable blocks or unfavourable structural surface combinations with the other structural surfaces. The ground water moves strongly. The intersection angle between the tunnel line and the main structural surface, and that between the tunnel line and the rock formation is less than 30°.</p>	<p>Surrounding rocks have a short self-stabilization period, so the vault usually collapses and the side walls are unstable. The time effect is obvious, so major deformation and fractures may occur. Rheological behaviour of soft rocks is obvious, so significant plastic deformation may occur.</p>	<p>In-time support is required during excavation. With shotcrete-bolting-mesh and steel arch frame used, closely followed support or advanced support is needed when the diameter of the tunnel is greater than 5m. Full lining can be provided if necessary. Pay attention to the rock frame period security.</p>
		<p>Medium-hard rocks are in thin stratified structure. Weak weathering zone is with the weak intercalated layer. With the joint fissure developed, the rock mass is broken with the mud partially contained. Different rock formations are poorly bonded. The ground water moves medially. The intersection angle between the tunnel line and the rock formation strike and that between the tunnel line and the rock formation is less than 30°.</p>		

Table B.1 (continued)

Surrounding rock type	Surrounding rock stability	Main engineering geological characteristics of surrounding rocks	Unlined tunnel self-stabilization and deformation	Support type
V	Extremely unstable	<p>Medium-hard rocks are intensely weathered. Affected by the geologic structure, the rock mass is broken with the joint fissure highly developed, irregular, open with mud, having poor occlusion force, and shows up in irregular fragmentation blocks. The ground water moves medially. The intersection angle between the tunnel line and the structural surface is less than 30° and the inclination is smooth.</p>	<p>Self-stabilization cannot be realized, so the side walls and vaults may collapse or easily deform. Collapse often occurs during excavation. Roof caving and ground settlement even occurs, leading to deformation and serious damage.</p>	<p>With poor excavation conditions, closely followed or advanced support, or full cross-section lining are required.</p>
		<p>Relatively-soft rocks or soft rocks are moderately weathered and intensely weathered. Affected by the geologic structure, the rock mass is broken with the joint fissure developed, and open with mud, has soft rock formation and diastrophism along the rock formation. There are a lot of air-facing cutting bodies. The ground water moves from medium to strong, which speeds up rock mass weathering and reduces shearing-assistant strength on the structural surface. The intersection angle between the tunnel line and the structural surface is greater than 30° and the rock formation inclination is less than 30°.</p>		
		<p>Completely weathered rocks in the loose gravel-soil uneven loose structure. The ground water moves from medium to strong.</p>		

**Appendix C**  
**(Informative)**

**Rock and soil permeability classification**

Rock and soil permeability classification of SHP plants shall meet regulations in table C.1.

**Table C.1 Rock and soil permeability classification**

Permeability classification		Permeability standards		Rock mass characteristics	Soil
		Permeability coefficient $K$ (mm/s)	Permeability rate $q$ (Lu)		
Infinitesimal permeability		$K < 10^{-5}$	$q < 0.1$	Intact rock, including rock mass with cracks of equivalence opening small than 0.025 mm	Clay
Slight permeability		$10^{-5} \leq K < 10^{-4}$	$0.1 \leq q < 1$	Including rock mass with cracks of equivalence opening 0.025 mm to 0.05 mm	Clay-silt
Low permeability	Lower	$10^{-4} \leq K < 10^{-3}$	$1 \leq q < 3$	Including rock mass with cracks with equivalent opening 0.05 mm to 0.1 mm	Silt, fine soil sand
	Middle		$3 \leq q < 5$		
	Upper		$5 \leq q < 10$		
Medium permeability		$10^{-3} \leq K < 10^{-1}$	$10 \leq q < 100$	Including rock mass with cracks with equivalent opening 0.1 mm to 0.5 mm	Sand and gravel
High permeability		$10^{-1} \leq K < 1$	$100 \leq q$	Including rock mass with cracks with equivalent opening 0.5 mm to 2.5 mm	Gravel-grit, grit
Pole-strength permeability		$1 \leq K$		Including through cavities or rock mass with cracks with equivalent opening greater than 2.5 mm	Boulders with even grain diameter

**Appendix D**  
**(Informative)**  
**Slope engineering geologic classification**

Rock and soil permeability classification of SHP plants shall meet regulations in table D.1.

**Table D.1 General slope engineering geologic classification**

Classification basis	Classification name	Classification characteristic description
Relationship with the engineering	Natural side slope	Slope that is not manually transformed
	Engineering slope	Slope that is manually transformed
Lithology	Rock slope	Slope consists of rocks
	Soil slope	Slope consists of soil layers
	Slope with rocks and soil combined	Slope consists of rocks in one part and soil layers in the other part
Deformation	Slope that is not deformed	Slope rock and soil bodies with no deformation and displacement
	Deformed slope	Slope rock and soil bodies with deformation and displacement
Slope angle $\theta$	Slight slope	$\theta \leq 10^\circ$
	Slope	$10^\circ < \theta \leq 30^\circ$
	Steep slope	$30^\circ < \theta \leq 45^\circ$
	Sharp slope	$45^\circ < \theta \leq 65^\circ$
	Extremely sharp slope	$65^\circ < \theta \leq 90^\circ$
	Adverse slope	$90^\circ < \theta$
Engineering slope height $H(m)$	Super high slope	$150 \leq H$
	High slope	$50 \leq H < 150$
	Medium slope	$20 \leq H < 50$
	Low slope	$H < 20$
Unstable slope volume $V(m^3)$	Extra-large landslide	$10 \times 10^6 \leq V$
	Large landslide	$1 \times 10^6 \leq V < 10 \times 10^6$
	Medium landslide	$100 \times 10^3 \leq V < 1 \times 10^6$
	Small landslide	$V < 100 \times 10^3$

Table D.2 Rock slope classification

Slope type	Main characteristic	Main factors that affect the stability	Main possible deformation and broken modes	Relationship with the engineering	Principle of treatment and methods and suggestions
Rock slope with blocky rocks	Magmatic rock or sedimentary rock on the huge-thick formation with relatively even uniform lithology	<ol style="list-style-type: none"> <li>1. Joint fissure cutting and filling</li> <li>2. Weathering characteristics</li> </ol>	Looseness, cracks and deformation are the main modes with unloading cracks regularly occurred and partial crumbling occurred sometimes	Generally, it is relatively stable. While, we should pay attention to the combination of unfavourable joints and analyse the possibility of partial collapse; when unloading cracks occur, pay attention to a partial collapse caused by leakage from water conductor structures on the slope.	<ol style="list-style-type: none"> <li>1. Anchor rock mass that may have partial crumbling.</li> <li>2. Slope drainage shall be properly arranged to prevent partial instability of the slope caused by water filling through cracks.</li> </ol>
The stratum is in the same direction as that of rock slope in slight tilting structure.	Hard bedded rocks with the slope surface and the rock formation surface in the same direction. The slope angle is greater than the rock formation angle and the rock formation surface is cut off by the slope surface.	<ol style="list-style-type: none"> <li>1. Stratum angle</li> <li>2. Rock formation surface shear strength</li> <li>3. Joint development characteristics and filling</li> </ol>	<ol style="list-style-type: none"> <li>1. Stretching sliding</li> <li>2. Upper deformation or creep deformation due to soft slope root</li> <li>3. Creeping along the soft rock strata</li> </ol>	The rock formation surface can be frequently cut off due to excavation. If there is soft rock strata, bedding slip can easily occur (especially on rainy days). On rainy days, the civil structure may be unstable.	<ol style="list-style-type: none"> <li>1. Prevention of bedding slip for soft rock strata</li> <li>2. Partial anchoring</li> <li>3. Soft rock strata removal and backfill</li> <li>4. Supporting engineering used for slip prevention</li> <li>5. Water drainage</li> </ol>
The stratum is in the same direction as the rock slope in steep tilting structure.	Hard bedded rocks with the slope surface and the rock formation surface in the same direction. The slope angle is smaller than the rock formation angle and the rock formation surface is not cut off by the slope surface.	<ol style="list-style-type: none"> <li>1. Development and filling of joint fissure, especially joint development</li> <li>2. Soft rock strata development</li> <li>3. Impacts of crack water</li> <li>4. Vibration</li> </ol>	<ol style="list-style-type: none"> <li>1. Surface rock formation creeps, deforms and dumps.</li> <li>2. Partial crumbling</li> <li>3. Slip</li> </ol>	Generally, it is relatively stable. While, slope and creep deformation may be caused by excavation in the thin-rock formation and regions with many soft rock strata distributed.	<ol style="list-style-type: none"> <li>1. The excavation slope shall not be greater than the rock formation angle. The rock formation cannot be cut off. A riding track cannot be set when the slope is high.</li> <li>2. Check the joint distribution characteristics and analyse combined structural surfaces with no unfavourable skid resistance factors.</li> </ol>



Table D.2 (continued)

Slope type	Main characteristic	Main factors that affect the stability	Main possible deformation and broken modes	Relationship with the engineering	Principle of treatment and methods and suggestions
Slope with rocks in reverse formation	Bedded rocks with the slope surface in the opposite direction from the rock formation surface	<ol style="list-style-type: none"> <li>1. Joint fissure distribution characteristics</li> <li>2. Distribution of lithology and soft rock strata</li> <li>3. Underground water crustal stress and weathering characteristics</li> </ol>	<ol style="list-style-type: none"> <li>1. Creep tilting and loose deformation</li> <li>2. Deformation occurs in the upper part when the soft rock strata are located at the slope foot.</li> <li>3. Partial crumbling and slip</li> </ol>	Generally, it is relatively stable. While, slope and creep deformation may be caused by excavation in thin-rock formation and regions with many soft rock strata distributed.	<ol style="list-style-type: none"> <li>1. Check joint fissure distribution characteristics and properly cut the slope to prevent partial crumbling and slip.</li> <li>2. Partial anchoring</li> </ol>
Slope with rocks in diagonal formation	Bedded rocks with the rock direction and the slope surface forming an angle	Joint fissure development	<ol style="list-style-type: none"> <li>1. Crumbling</li> <li>2. Sphenoid slide</li> </ol>	Generally, it is relatively stable.	Check joint fissure distribution occurrence, analyse the possibility of a sphenoid slide, and properly clean or anchor the slope if necessary.
Rock slope with broken rocks	Slope with hard rocks that has irregular joint fissure that is strongly developed	<ol style="list-style-type: none"> <li>1. Degree of rock body crushing</li> <li>2. Joint fissure development</li> <li>3. Impacts of crack water</li> <li>4. Vibration</li> </ol>	<ol style="list-style-type: none"> <li>1. Crumbling</li> <li>2. Collapse</li> </ol>	Partial collapse can easily occur, affecting the civil structure safety; water permeable, unfavourable to dam shoulder stability and load bearing	<ol style="list-style-type: none"> <li>1. Properly clean and select a stable slope foot.</li> <li>2. Anchor ejection protection on the surface</li> <li>3. Water drainage</li> </ol>

Table D.3 Soil slope classification

Slope type	Main characteristic	Main factors that affect the stability	Main possible deformation and broken modes	Relationship with the engineering	Principle of treatment and methods and suggestions
Clay slope	It mainly consists of clay and is hard when dry and crumbles after extension when wet.	<ol style="list-style-type: none"> <li>1. Mineral composition, especially content of hydrophilic, expansion and soluble minerals.</li> <li>2. Effects of water</li> <li>3. Effects of freeze thawing</li> </ol>	<ol style="list-style-type: none"> <li>1. Clay with expansive hydrophilic mineral can easily cause a landslide; high slope can cause a high-speed landslide due to slope foot creeping.</li> <li>2. Peeling off caused by freeze thawing</li> <li>3. Collapse</li> </ol>	Reservoir or channel clay slope landslide may occur due to impoundment and water delivery. Pay attention to adverse impacts caused by wide-range clay sliding; engineering slopes in cold regions may be peeled off or broken due to freeze thawing.	<ol style="list-style-type: none"> <li>1. Waterproof and water draining</li> <li>2. Cut slope presser foot</li> <li>3. Slope with freeze thawing peeling: grass planting or protection coverage, slope water draining and slope dry</li> </ol>
Sandy soil and slope	It has characteristics of mainly sand, loose construction, low cohesive force and high water permeability, and includes completely weathered granite on the thick-rock formation and elurium.	<ol style="list-style-type: none"> <li>1. Granular component and uniformity coefficient</li> <li>2. Contains moisture</li> <li>3. Vibration</li> <li>4. Effects of external water and underground water</li> <li>5. Compaction rate</li> </ol>	<ol style="list-style-type: none"> <li>1. Slope with saturated sandy soil can easily have liquefaction landslide under the effect of the vibratory force.</li> <li>2. Piping and flowing soil</li> <li>3. Collapse and peeling off</li> </ol>	Channel slope or other civil structure slope in a high earthquake-intensity area have liquefaction landslides when an earthquake occurs. Mechanical vibration may also have partial landslide. Piping and flowing soil may occur in the drainage of the foundation pit.	<ol style="list-style-type: none"> <li>1. Water drainage</li> <li>2. Cut slope presser foot</li> <li>3. Take vibro-compaction and closing measures in advance and pay attention to drainage.</li> </ol>
Loess slope	It mainly includes powder particle in even texture. It has high calcium content, low natural moisture content, no bedding. Its columnar jointing develops. It is dry, and when dry it partially collapses shows up in solidification structure or multiple structure when wet.	It is mainly affected by water. It can collapse by water, the slope is soaked by water, the clay pan argillization occurs due to water infiltration.	<ol style="list-style-type: none"> <li>1. Crumbling</li> <li>2. Tension crack</li> <li>3. Collapse</li> <li>4. The high slope may have a high-speed landslide.</li> </ol>	The channel slope may have landslide due to water; the bank slope of reservoir may collapse or slide due to soaking of the reservoir water; the underground water level may rise to cause loess collapse and brae cracking; humidifying causes ancient landslide revival.	<ol style="list-style-type: none"> <li>1. Waterproof and drainage shall prevent water conductor structure from leakage as far as possible.</li> <li>2. Reasonable slope cutting</li> <li>3. Monitor and forest the sloughing bank and ancient landslide.</li> </ol>

Table D.3 (continued)

Slope type	Main characteristic	Main factors that affect the stability	Main possible deformation and broken modes	Relationship with the engineering	Principle of treatment and methods and suggestions
Soft soil slope	It mainly consists of soil with low shearing strength, such as sludge, peat and mucky soil, and has serious plastic flow deformation.	<ol style="list-style-type: none"> <li>Soft soil (characteristics of low shearing strength, high compressibility and plastic flow deformation)</li> <li>Exogenous process and vibration</li> </ol>	<ol style="list-style-type: none"> <li>Landslide</li> <li>Plastic flow deformation</li> <li>Collapses; it is difficult to form a slope;</li> </ol>	The channel cannot form when going through the soft soil area due to plastic flow deformation; when the slope has soft soil at its foot, the slope may collapse due to flowing deformation.	<ol style="list-style-type: none"> <li>Thorough removal</li> <li>Avoid</li> <li>Pressure back filling</li> <li>Water drainage solidification</li> </ol>
Expansive soil slope	It has special physical and mechanical properties. Its internal friction angle is small for rich montmorillonite and other expandable minerals and obvious dry-wet effects.	<ol style="list-style-type: none"> <li>Dry and wet climatic changes</li> <li>Effects of water</li> </ol>	<ol style="list-style-type: none"> <li>Shallow landslide</li> <li>Superficial layer disintegration</li> </ol>	Continuous slide or collapse caused by natural conditions changes and surface layer expansion and disintegration after slope excavation	<ol style="list-style-type: none"> <li>Do not change the containing water of the soil as far as possible.</li> <li>The protective layer is reserved. Cover it soon after excavation for moisture preservation.</li> <li>Select a stable slope angle.</li> <li>Drainage reinforcing and protection closure</li> </ol>
Dispersive soil slope	It consists of medium plastic clay and silty clay with a certain amount of sodium montmorillonite, which may be water-washed, especially water with low saltiness. The surface soil may successively fall off and be washed away by flowing water in suspension liquid or soil particles and be quickly scattered.	<ol style="list-style-type: none"> <li>Environmental water with low saltiness</li> <li>Water solution in holes with high sodium content and high alkalinity medium</li> <li>Naked soil in contact with water</li> </ol>	<ol style="list-style-type: none"> <li>Washout holes and passages</li> <li>Piping, collapse and corrosion holes</li> <li>Collapse, crumble and landslide</li> </ol>	Dam and channel slope has random deformation and fracture or potential crisis during construction and operation.	<ol style="list-style-type: none"> <li>It should not be used as foundation or construction materials.</li> <li>Totally closed, separating water from soil</li> <li>Loaded filter setting</li> <li>Soil character improvement</li> <li>Engineering environment water improvement for saltiness increase</li> </ol>

Table D.3 (continued)

Slope type	Main characteristic	Main factors that affect the stability	Main possible deformation and broken modes	Relationship with the engineering	Principle of treatment and methods and suggestions
Gravelly soil slope	This slope consists of hard rock fragments and sandy soil particles or gravelly soil, and shows up in accumulation structure, slide rock mixed structure and multiple structure.	<ol style="list-style-type: none"> <li>1. Clay particle content and distribution characteristics</li> <li>2. Slope water containing</li> <li>3. Subterranean occurrence</li> </ol>	<ol style="list-style-type: none"> <li>1. Soil landslide</li> <li>2. Collapse</li> </ol>	Partial Collapse caused by construction excavation. When being used as bank slope of reservoir, the slope may partially collapse or crack in the upper part due to reservoir filling. Sharp decline of water in the reservoir may cause landslide.	<ol style="list-style-type: none"> <li>1. Properly select a stable slope angle.</li> <li>2. Slope drainage strengthening prevents water injection into the slope.</li> <li>3. Monitor the key sections of the reservoir bank in the storage period.</li> </ol>
Slope with rocks and soil combined	The slope is soil layer on the upper part and rock formation on the lower part, or the rock formation on the upper part and soil layer on the lower parts, with multiple layers overlapping.	<ol style="list-style-type: none"> <li>1. Subterranean occurrence</li> <li>2. Soil layer being soaked by water and with water leaking into the body.</li> </ol>	<ol style="list-style-type: none"> <li>1. The soil layer slides along subterranean.</li> <li>2. The soil layer partially clamps.</li> <li>3. The upper rock mass creeps or staggers along the soil layer.</li> </ol>	When the dip angle between the bed rock of the superimposed rock mixed slope and the slope is large, a slide may occur along the bedrock after impoundment, rainstorm and vibration.	<ol style="list-style-type: none"> <li>1. Properly select a stable slope angle.</li> <li>2. Slope drainage strengthening prevents water injection into the slope.</li> <li>3. Monitor the key sections of the reservoir bank during the storage period.</li> </ol>

Table D.4 Deformed slope classification (by deformation characteristics)


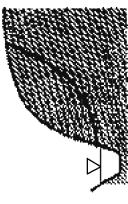
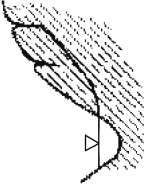
Deformation type	Slope classification name	Schematic profile	Main characteristic	Main factor that affect the stability	Relationship with water resources and hydropower engineering	Principle of treatment and methods and suggestions
Tension crack deformation	Rock slope		The rock mass extends outwards from the slope with slight angle change, but there is no shear displacement or spallation rolling. The slight angle change mainly occurs in hard rocks on the thick-rock formation or in blocky structure, especially when there are soft layers (such as coal seam and fault fracture zone) at the foot.	<ol style="list-style-type: none"> <li>1. The soft layer at the slope foot is further softened or washed</li> <li>2. Vibration</li> <li>3. Rainstorm and impeded drainage</li> <li>4. Stress relief</li> </ol>	Low water permeability is unfavourable to dam shoulder seepage-proofing; large deformation vertical to cracks is unfavourable to the pressure-bearing of an arch dam; crumbling rock mass cause disasters when unstable.	<ol style="list-style-type: none"> <li>1. Prevent the situation where the soft layer at the slope foot is further softened or manually damaged.</li> <li>2. Control the explosion scale and method.</li> <li>3. Consolidation grouting or anchoring</li> <li>4. Explosion load shedding if necessary</li> </ol>
	Tension crack deformation slope					
Sliding deformation	Clay landslide		The clay is hard when dry and clumps when wet. Drainage difficulty, continuous rainfall or humidifying can reduce the strength and easily lead to a slope slide.	<ol style="list-style-type: none"> <li>1. Effects of water: rainstorm soaking, manual water injection and drainage difficulty</li> <li>2. Vibration: earthquake and exposure</li> <li>3. Improper excavation mode: foot cutting, head loading and landslide are excavation from bottom to upper are inappropriate for civil structure layout.</li> </ol>	Landslide is unfavourable to channel slope; pay attention to sliding after reservoir area impoundment and relocation of people from reservoir area in hill and gorge areas.	<ol style="list-style-type: none"> <li>1. Pay attention to the excavation mode and procedure.</li> <li>2. Drainage of the slope surface and the slope body</li> <li>3. Supporting structure, slide-resistant pile, etc.</li> </ol>
	Soil landslide		The vertical fractures develop and are easy for water permeability and clamp. Landslide at the loess plateau edge or high and steep slope of the gorge is serious. When there is a clay layer, the slope can easily slide after continuous heavy rain.			

Table D.4 (continued)

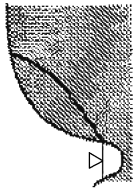


Deformation type	Slope classification name	Schematic profile	Main characteristic	Main factor that affect the stability	Relationship with water resources and hydropower engineering	Principle of treatment and methods and suggestions
Sliding deformation	Clay Landslide		It has high water permeability, so a variation-caused liquidation landslide may occur when there is a saturated sand layer. The slope may slide easily when it is difficult to drain water due to a rainstorm.	<ol style="list-style-type: none"> <li>1. Effects of water: rainstorm soaking, manual water injection and drainage difficulty</li> <li>2. Vibration: earthquake and exposure</li> <li>3. Improper excavation mode; foot cutting, head loading and landslide are excavation from bottom to upper are inappropriate for civil structure layout.</li> </ol>	Landslide is unfavourable to channel slope; pay attention to sliding after reservoir area impoundment and relocation of people from reservoir area in hill and gorge areas.	<ol style="list-style-type: none"> <li>1. Pay attention to the excavation mode and procedure.</li> <li>2. Drainage of the slope surface and the slope body</li> <li>3. Supporting structure, slide-resistant pile, etc.</li> </ol>
	Soil landslide		It has earth and stone mixed, shows up in loose structure, has high water permeability, mainly on the slope elurium, and always slides along the basement contact surface.	<ol style="list-style-type: none"> <li>1. Rock strength</li> <li>2. Effects of water</li> <li>3. Slope grade and height</li> </ol>	The landslide is on a large-scale, may reoccur after conditions deterioration, and is unsuitable for the layout of civil structures.	<ol style="list-style-type: none"> <li>1. Avoid</li> <li>2. Removal or partial removal</li> <li>3. Water drainage</li> </ol>
Sliding deformation	Homogenous soft rock landslide		The slip mass is mainly controlled by the rock strength. The sliding surface always shows up in arc or cut layer, which is not always consistent with the weak structural surface, especially for large-scale landslides.			

Table D.4 (continued)

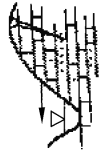


Deformation type	Slope classification name	Schematic profile	Main characteristic	Main factor that affect the stability	Relationship with water resources and hydropower engineering	Principle of treatment and methods and suggestions
Sliding deformation	Bedding landslide		Landslide generally occurs along the rock formation, which is mainly controlled by rock formation in status.	<ol style="list-style-type: none"> <li>1. Soft rock strata or bedding shearing strength</li> <li>2. Erosion cutting and improper excavation</li> </ol>	If it is used as civil structure slope, it will affect the civil structure security. It is unsuitable as a channel slope.	<ol style="list-style-type: none"> <li>1. Removal or partial removal</li> <li>2. Water drainage</li> <li>3. Supporting or anchoring when the scale is small.</li> </ol>
	In sequent landslide		The sliding surface cuts off the layer, so the slip mass status is controlled by several groups of joint fissures.	<ol style="list-style-type: none"> <li>1. Joint cutting</li> <li>2. Rock mass strength</li> <li>3. Effects of water</li> <li>4. Gently inclined structural surface and soft rock strata</li> </ol>	It is not suitable for being slopes of channels or other civil structures.	<ol style="list-style-type: none"> <li>1. Removal or partial removal</li> <li>2. Water drainage</li> <li>3. Supporting or anchoring when on a small scale.</li> </ol>
	Crushing wall rock landslide		The joint fissures are densely developed. The sliding surface occurs from the fractured rock mass and the sliding surface is controlled by the fractured rock mass strength.	<ol style="list-style-type: none"> <li>1. Joint fissure cutting</li> <li>2. Rock mass strength</li> <li>3. Effects of water</li> </ol>	Water permeability is not highly conducive to the seepage-proofing of the dam shoulder. It is unsuitable as a channel slope.	<ol style="list-style-type: none"> <li>1. Slope cutting and clearing</li> <li>2. Water drainage</li> <li>3. Supporting when on a small scale.</li> </ol>

Table D.4 (continued)

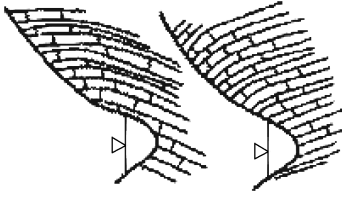
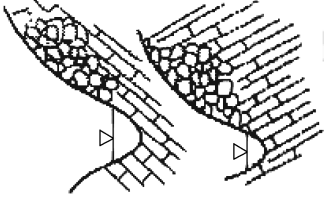
Deformation type	Slope classification name	Schematic profile	Main characteristic	Main factor that affect the stability	Relationship with water resources and hydropower engineering	Principle of treatment and methods and suggestions
Creep deformation	Dump creep deformation slope		<p>The rock mass tilts outwards; the succession of the strata is out of order and the rock mass loosens; the fracture develops; the relative movement between stratum; dump amplitude reduces gradually by depth; reverse banks occur sometimes on the slope surface.</p>	<ol style="list-style-type: none"> <li>1. Excavation angle</li> <li>2. Vibration</li> <li>3. Water filling and drainage difficulty</li> </ol>	<p>Unfavourable anti-permeability; large subsidence deformation; unfavourable to engineering loading bearing; continuous collapse caused by excavation angle</p>	<ol style="list-style-type: none"> <li>1. Removal from top to bottom; the excavation angle should not be greater than the natural slope angle.</li> <li>2. Seepage-proofing for drainage of the slope surface and the slope body</li> <li>3. If the deformation is fast, an excavation protective layer shall be reserved.</li> </ol>
	Loose creep deformation slope		<p>The succession of strata is out of order; the rocks loosen and are not obviously separated from the lower complete rock formation. This condition occurs after the development of a serious dumping.</p>	<ol style="list-style-type: none"> <li>1. Excavation angle</li> <li>2. Vibration</li> <li>3. Water filling and drainage difficulty</li> </ol>	<p>It is unfavourable to seepage-proofing and bearing; the excavation angle often causes continuous collapse. The large-scale loosened bodies on the reservoir bank may deform after impoundment, so it is unsuitable to be the slopes of abutment of the dam, tunnel surface, channel and civil structure.</p>	<ol style="list-style-type: none"> <li>1. Keep the original status and naturally stable.</li> <li>2. Drainage of the slope surface and the slope body</li> <li>3. Removal from top to bottom; the excavation angle should not be greater than the natural slope angle.</li> </ol>



Table D.4 (continued)

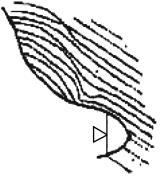
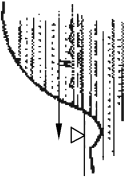
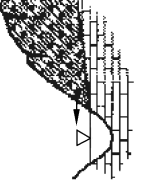
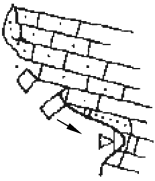

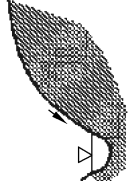
Deformation type	Slope classification name	Schematic profile	Main characteristic	Main factor that affect the stability	Relationship with water resources and hydropower engineering	Principle of treatment and methods and suggestions
Creep deformation	Distorted creep deformation slope		Plastic thin rock formation often occurs; the rock formation bends outwards with few fractures ( pay attention to difference from the tectonic deformation); movement between stratum occurs with non-obvious separation fractures.	<ol style="list-style-type: none"> <li>1. Effects of rock flowing deformation</li> <li>2. Effects of water</li> <li>3. Vibration</li> <li>4. Excavation unloading and improper excavation mode</li> </ol>	Partial bedding sliding or slow distortion affects the civil structure security. Except surface layers, water permeability is not high generally.	<ol style="list-style-type: none"> <li>1. Slope cutting for removal; the excavation angle shall be appropriate.</li> <li>2. Reserving excavation protection layer</li> <li>3. Partial anchoring</li> </ol>
	Rock slope	Plastic flow creep deformation slope		Brittle rocks move slowly along the lower plastic soft rock strata.	<ol style="list-style-type: none"> <li>1. Further argillization occurs to the ductile bed under the effects of water.</li> <li>2. Flowing deformation effect on the soft formation.</li> </ol>	Slope after the cutting part moves slowly or partially collapses, which affects the civil structure security. The slope can easily slide when being used as the channel or reservoir slope.
Creep deformation	Soil creep deformation slope		Soil plastic creep deformation or flowing may lead to upper soil mass fractures, tilting or slight movement along the creep deformation formation, or even a landslide or collapse in serious situations. It is a forewarning of slide deformation.	<ol style="list-style-type: none"> <li>1. Effects of water</li> <li>2. Soil at the slope foot or the broken soil body may have flowing deformation when wet.</li> <li>3. Slope soil flowing deformation under the effects of the long-term action of gravity</li> </ol>	Landslide may occur when the slope encounters water or vibration. This slope shall not be used as the channel or civil structure slope.	<ol style="list-style-type: none"> <li>1. Excavation by the stable slope foot</li> <li>2. Clear</li> <li>3. Drainage of the slope surface and the slope body</li> </ol>

Table D.4 (continued)

Deformation type	Slope classification name	Schematic profile	Main characteristic	Main factor that affect the stability	Relationship with water resources and hydropower engineering	Principle of treatment and methods and suggestions
Collapse deformation	Rock (soil) slope		Steep slope; the upper rock (soil) body is suddenly separated from the mother rock, rolls over or falls onto the slope foot. Soil blocks often accumulate at the slope foot.	<ol style="list-style-type: none"> <li>1. Weathering and freezing expansion</li> <li>2. Rainstorm and impeded drainage</li> <li>3. Vibration</li> <li>4. Slope foot water erosion softening</li> </ol>	Deformation can rapidly affect the construction civil structure security; the accumulation is loosened with high water permeability and is unfavourable to seepage-proofing; the debris sinks and deforms unevenly.	<ol style="list-style-type: none"> <li>1. Remove the dangerous rocks to protect the civil structure.</li> <li>2. Partial anchoring and supporting</li> <li>3. When the foundation is built using debris, special seepage-proofing and reinforcement treatment is required.</li> </ol>
	Crumble deformation slope					
Collapse deformation	Rock (soil) slope		Slope rock (soil) body collapses and slides partially or wholly. The sliding surface is not regularly flat. The slope may clamp partially and is compound type deformed slope with sliding deformation, creep deformation and looseness.	<ol style="list-style-type: none"> <li>1. Plastic flow formation creep deformation</li> <li>2. Rainstorm and impeded drainage</li> <li>3. Vibration</li> <li>4. Unfavourable lithological association and structural surface</li> </ol>	Loose debris with high water permeability can easily sink or deform unevenly. It may partially continue to slide after being soaked.	<ol style="list-style-type: none"> <li>1. Slope surface seepage-proofing and slope body drainage</li> <li>2. Clear</li> <li>3. Partial supporting</li> </ol>
	Collapse deformation slope					
Peeling deformation	Rock (soil) slope		Clay slopes in high and cold areas peel off in the surface layer due to freeze-thaw actions. Hard clay slopes in southern areas may peel off due to dry-wet effects; the intense weathering mud rock formation peels off, which has no deep effects. Continuous peeling off is allowed.	<ol style="list-style-type: none"> <li>1. Effects of freeze thawing</li> <li>2. Dry-wet effects</li> <li>3. Weathering</li> </ol>	Channel or other engineering slopes are loose on the surfaces and collapse, increasing the difficulty maintaining.	<ol style="list-style-type: none"> <li>1. Grass planting slope coverage for protection</li> <li>2. Water drainage</li> <li>3. The protective layer is reserved.</li> </ol>
	Peeling deformation slope					

## Appendix E (Informative)

### Environmental water-based corrosion evaluation

E.1 Evaluation of concrete corrosion in the environmental water shall comply with the regulations in Table E.1.

**Table E.1 Evaluation standards for concrete corrosion in the environmental water**

Corrosion type	Corrosion judge basis	Corrosion degree	Threshold indicators
General acid	PH value	Non-corrosive Weak-corrosive Moderate-corrosive Strong-corrosive	pH>6.5 6.5≥pH>6.0 6.0≥pH>5.5 pH≤5.5
Calcareous type	Corrosion CO <sub>2</sub> content (mg/L)	Non-corrosive Weak-corrosive Moderate-corrosive Strong-corrosive	CO <sub>2</sub> <15 15≤CO <sub>2</sub> <30 30≤CO <sub>2</sub> <60 CO <sub>2</sub> ≥60
Bicarbonate type	HCO <sub>3</sub> <sup>-</sup> Content (mmol/L)	Non-corrosive Weak-corrosive Moderate-corrosive Strong-corrosive	HCO <sub>3</sub> <sup>-</sup> >1.07 1.07≥HCO <sub>3</sub> <sup>-</sup> >0.70 HCO <sub>3</sub> <sup>-</sup> ≤0.70 —
Magnesium	Mg <sup>2+</sup> Content (mg/L)	Non-corrosive Weak-corrosive Moderate-corrosive Strong-corrosive	Mg <sup>2+</sup> <1 000 1 000≤Mg <sup>2+</sup> <1 500 1 500≤Mg <sup>2+</sup> <2 000 Mg <sup>2+</sup> ≥2 000
Sulphate	SO <sub>4</sub> <sup>2-</sup> Content (mg/L)	Non-corrosive Weak-corrosive Moderate-corrosive Strong-corrosive	SO <sub>4</sub> <sup>2-</sup> <250 250≤SO <sub>4</sub> <sup>2-</sup> <400 400≤SO <sub>4</sub> <sup>2-</sup> <500 SO <sub>4</sub> <sup>2-</sup> ≥500

E.2 Environmental water-based evaluation of rebar corrosion in the reinforced concrete structure shall comply with the regulations in Table E.2.

**Table E.2 Standards for environmental water-based evaluation of rebar corrosion in the reinforced concrete structure**

Corrosion judge basis	Corrosion degree	Threshold indicators
Cl-Content(mg/L)	Weak-corrosive	100~500
	Moderate-corrosive	500~5 000
	Strong-corrosive	>5 000

E.3 Environmental water-based steel-structure corrosion evaluation shall comply with the regulations in Table E.3.

**Table E.3 Standards for environmental water-based steel-structure corrosion evaluation**

Corrosion judgement basis	Corrosion degree	Threshold indicators
pH value, (Cl <sup>-</sup> + SO <sub>4</sub> <sup>2-</sup> ) content (mg/L)	Weak-corrosive	pH value: 3-11, (Cl <sup>-</sup> + SO <sub>4</sub> <sup>2-</sup> ) < 500
	Moderate-corrosive	pH value: 3-11, (Cl <sup>-</sup> + SO <sub>4</sub> <sup>2-</sup> ) ≥ 500
	Strong-corrosive	pH < 3, (Cl <sup>-</sup> + SO <sub>4</sub> <sup>2-</sup> ) any concentration