UNITED NATIONS
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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Development of Small Hydropower Plants

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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).

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 30MW.

- 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 areal geology and reservoirengineering 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 It is necessary to define the design intent and engineering characteristics, and perform engineering geological investigation according to the actual situation.

4.1.2 It is necessary to collect and review the existing geological data before carrying out field work, to perform site survey, learn about the natural conditions and working conditions on site and prepare the engineering geological investigation program in combination with the engineering design plan.

4.1.3 It is necessary to carry out the investigations by stages according to the investigation program, and to ensure a reasonable investigation period and workload.

4.1.4 It is necessary to comprehensively utilize various investigation methods and reasonably arrange the investigation work and enhance the synthesis and analysis of data in accordance with the engineering features, the complexity of the geological and topographical conditions as well as requirements for the investigation depth in various investigation stages. Carry out appropriate geological surveying and mapping, geophysical prospecting, drilling, trench exploration and indoor testing, supplemented by adit exploration and field testing depending on the situation.

4.1.5 The investigation of natural construction materials shall meet the accuracy and design requirements for various investigation stages.

4.1.6 The project site should try to avoid serious seepage, major landslides and collapse, creep, dangerous rock mass, debris flow, active fault and other adverse geological problems as well as cultural relics and ecological environment protection areas. Pay attention to the analysis of environmental geological problems that may arise from engineering construction.

## 4.2 Investigation program

4.2.1 Before carrying out the investigation, it is necessary to prepare the engineering geological investigation program in accordance with the investigation assignment and in combination with the design plan.

4.2.2 The engineering geological investigation program shall include the following contents:

a) Project profile, project structures, 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, based upon which the investigation is performed;

d) Investigation task requirement, 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 can be determined by engineering geological analogy and experience-based judgment; field and laboratory tests may be performed when necessary.

4.3.2 The geotechnical parameters of the earth base shall be determined on the basis of field and laboratory test results, and in combination with engineering geological analogy and experience-based judgment.

# 5 Areal geology

## 5.1 General provisions

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

5.1.2 It is necessary to determine the key emphasis of the actual investigation work according to the specific regional geological characteristics of the project site:

a) In the karst area, it is necessary to particularly learn about the development situation of the karst and the hydrogeological conditions;

b) In the area with relatively strong seismic activities, it is necessary to pay special attention to the geologic structure and fault activities;

c) In the distribution area of the quaternary system, it is necessary to establish the type of quaternary sediment, the development history of the river and the development situation of the terrace.

## 5.2 Topography and geomorphology.

5.2.1 In the topography and geomorphology investigation, it is necessary to reasonably use the topographic and geomorphic conditions 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, it is necessary to study the following information in the region with satellite images and aerial photos on the basis of collecting and analysing the latest topographic data for 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 and interrelations between different geomorphic units.

## 5.3 Geologic structure

5.3.1 For geologic structure investigation, it is necessary to take fully into consideration the strength and permeability of the geologic structure and to avoid the folds and faults.

5.3.2 For geologic structure investigation, it is necessary to collect the geological data in the region. The geological mapping of small scale and the geological data of the completed or planned projects near the proposed project

5.3.3 After analysing and sorting the collected data, geological surveying and mapping may be performed for the geologic structure in the proposed project area to review its accuracy.

5.3.4 When no existing geological data is available, it is necessary to perform a geological survey in the project area and within a certain scope around it 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 tectonic stability, judge the possibility of the proposed SHP project site being damaged by active fault or seismic activity in the coming 50 to 100 years, the damage intensity and damage probability, and then propose the geological parameters for aseismic design of the SHP 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.

5.4.3 Regional structural stability and seismic survey focus on data collection, including the collecting of data concerning regional formation lithology, geologic structure, active fault, ground motion parameters or seismic basic intensity, and historical seismological data, etc. Assess and judge the overall stability of the regional structure of the project area at the macro level, 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 favourable earthquake resistance sections should be selected as the project layout, while 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, it is necessary to study its rule of occurrence and development, its causes, the factors influencing its occurrence and development, the formation condition and mechanism, and the development process and stages, and make correct assessments and formulate reasonable control measures.

5.5.2 It is necessary to preliminarily judge the geophysical phenomenon which might develop in the project area at the macro level by analysing the basic geological data concerning the topography and geomorphology and geologic structure, establish the type and development degree of various geophysical phenomena in the upstream/downstream area of the basin through field geological surveying and mapping, ascertain the adverse geophysical phenomena in the reservoir area, dam site, plant site and particularly along the water diversion route, and arrange ground observation like drilling exploration, geophysical prospecting, Test Pits and Trenches as well as long-term observation when necessary.

## 5.6 Hydrogeology

5.6.1 It is necessary to ascertain the adverse influence of groundwater on the construction of the SHP project and propose control measures by researching the distribution and formation rules of the groundwater as well as the physical property and chemical components of the groundwater.

5.6.2 Main working method for the hydrogeological survey includes data collection, ground survey, exploration, hydrogeological testing, water chemical testing and observation; the key emphasis in the work shall include the lithology and burial and distribution conditions of the main aquifers, the cause, type, recharge-discharge conditions of groundwater in various aquifers 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 is a kind of comprehensive survey performed for the purpose of demonstrating the engineering geological problems caused by the reservoir filling, and is to investigate the reservoir seepage, reservoir immersion, reservoir banks/rim slope stability, reservoir sedimentation and reservoir-induced earthquake. In the case of an unstable slope, it is necessary to evaluate the underground hydrogeological conditions.

## 6.2 Reservoir seepage

6.2.1 During the reservoir seepage investigation, it is necessary to ascertain whether there are geographic and geomorphic conditions, lithologic and geologic structure conditions and hydrogeological conditions which would lead to reservoir seepage, to explore and study the form of reservoir seepage, assess the possible reservoir seepage amount and to propose suggestions and measures for preventing reservoir seepage.

6.2.2 The study of reservoir seepage is mainly performed by engineering geological surveying and mapping to ascertain whether the conditions which might lead to seepage exist:

a) The low thin area between rivers exists 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 exists between the reservoir area and the downstream tributary of the dam;

c) The reservoir basin is a water permeable stratum composed of sand, sand gravel and rickle with high water permeability;

d) The reservoir basin is composed of soluble rocks like limestone and gypsum, and seepage passage is formed by the karst topography, pipeline and grike;

e) The reservoir basin and thin watershed are composed of gravels with loose structure;

f) The columnar jointing is 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 river bed 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.

6.2.3 Through the analysis of the geological conditions in 6.2.2, determine the form and type of seepage, estimate the seepage amount of the reservoir and propose a feasible seepage treatment suggestion.

## 6.3 Reservoir immersion

6.3.1 During the reservoir immersion investigation, it is necessary to ascertain 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 small towns, forest and farmlands, etc. around the reservoir area, determine the immersion affected scope and propose prevention and control measures.

6.3.2 During the reservoir immersion investigation, it is necessary to investigate the rock stratum, groundwater level and the relationship between the recharge and discharge of groundwater within a certain scope above the normal pool level of the reservoir area through the geological surveying, mapping and general geological prospecting work.

6.3.3 The following sections in the reservoir may be judged to be sections which would not be immersed:

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

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

6.3.4 The following sections in the reservoir area may be judged to be sections where secondary salinization could not happen:

a) Wet climatic 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 During the reservoir banks stability investigation, it is necessary to ascertain 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 possibility of bank collapse.

6.4.2 It is necessary to learn about the form, formation lithology and physico-geological function of the reservoir banks by engineering geological surveying and mapping and general prospecting means, establish the stability of the reservoir banks without reservoir filling, study and predict the possibility and scope of bank slumps of the soil bank slope induced by waves and scouring under the effect of reservoir water and waves.

6.4.3 It is necessary to ascertain the geological and topographical conditions of reservoir rock banks, 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, investigate and predict the possibility of landslide and rockfall for reservoir rock banks 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 work should be arranged. Predicting and evaluating the slope stability and the scope and scale of possible deformation and failure under different reservoir water level conditions. Assess the possible effects of deformation and instability.

6.4.5 Propose suggestions on reservoir banks stability control measures on the basis of the above analysis and evaluation.

### 6.5 Reservoir sedimentation

6.5.1 During the reservoir sedimentation investigation, it is necessary to ascertain the scour and erosion situation of the upstream rivers and gully of the reservoir. The source of the sediment runoff in the reservoir area, assess the reservoir sedimentation problems and propose suggestions on control measures.

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. It is necessary to learn about the engineering geological conditions of reservoir area 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 survey in the dam site area should carry out the engineering geological survey work according to the accuracy requirements of three different design stages of the pre-feasibility study and feasibility study. The main contents include 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 and provide engineering geological data for the engineering design.

### 7.2 Pre-feasibility study stage

7.2.1 In the pre-feasibility study stage, it is necessary to preliminarily analyse the engineering geological conditions and the main engineering geological problems in the site selection scheme, and to demonstrate the feasibility of hydropower station construction from the perspective of engineering geology. It is necessary to particularly investigate the following information:

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 involves data collection and geological surveying and mapping. When selecting the working methods and arranging the investigation work, it is necessary to meet the following requirements:

a) Geological surveying and mapping: When the engineering geological condition is relatively simple, the geologic map of the reservoir area may be adopted, while an engineering geological map of the dam area may not be necessary; 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 for 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 and in combination with the exploration profile;

d) The drilling usually 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 river bed and the damshoulders of both banks;

e) For a rock-based dam site, the depth of drilling in the river bed 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 should 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 can be conducted for the over burden 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 can 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 should be included in this stage of the engineering geological investigation:

a) Preliminary identification of the topographic and geomorphic features of each selected dam site, especially gull, bealock, ancient river channels and river bed and deep groove;

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, ancient 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 corrosiveness of the concrete in each selected dam area. In special areas, the investigation of ancient river channels should 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) Put forward the physical and mechanical parameters of all the kinds of rock and soil, and preliminarily classify the rock mass of the dam foundation. Classify the dam bedrock by engineering geology. For details, see Appendix A.

7.3.2 When selecting the working methods and arranging the investigation work, it is necessary to meet the following requirements:

a) Geological surveying and mapping; 1:2 000 to 1:500 scale engineering geological map for the dam areashall be drawn;

b) Layout of the exploration work: a small amount of geophysical exploration and drilling work should be adopted. Each comparative dam area should be combined with the layout of the building to have at least a representative exploration section line, which is generally arranged at the axis of the retaining dam and spillway;

c) The exploration line for an earth and rockfill dam shall be arranged along the seepage control line or axis of the dam; the exploration line for concrete dams like gravity dams and arch dams shall be arranged along the axis of the dam; 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;

d) 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 river bed and the dam shoulders on both banks. The spacing between drill holes should not be more than 50 m;

e) For a rock-based dam site, the depth of drilling in the river bed 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;

f) For a soil-based dam site, the drilling depth should not be less than the dam height; if the soft layer orhighly-pervious bed is distributed in the dam foundation, the drilling depth shall be 5 m to 10 m into therelative confining bed of the solid soil layer or base rock;

g) 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;

h) For concrete dams, particularly the arched 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;

i) The borehole shall be hydrologically tested in sections, the bedrock should be subjected to the water pressure test, and the fractured bedrock which cannot be subjected to the water pressure test should be subjected to the water injection test; the Quaternary overburden should be subjected to the water injection test or the pumping test; during the drilling process in the karst area, the groundwater level should be observed and tracer tests should be carried out if necessary;

j) At least a group of surface water and a group of groundwater shall be sampled for water quality analysis to assess its corrosivity to the concrete. For details, see Appendix B;

k) When it is necessary to use the overburden as the dam foundation, the sampling, standard penetration test or conical dynamic penetration tests should be carried out according to the nature of the soil layer; the effective groups of sampling in each soil layer should not be less 6;

l) Rock base shall be determined by engineering geological analogy and experience-based judgment, and in combination 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, and in combination with engineering geological analogy and experience-based judgment.

# 8 Engineering geological investigation of the water delivery route

## 8.1 General provisions

The engineering geological investigation of the water transmission line should be carried out according to the accuracy requirements of two different design stages: pre-feasibility study and feasibility study. The engineering geological and hydrogeological conditions along the water transmission 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, it is necessary to assess/investigate the engineering geological conditions and the main engineering geological problems in the comparison schemes of the water delivery route, and investigate the following contents particularly:

a) The topographic and geomorphological features, physical and geological phenomena in the water conveyance 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) 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 the karst area;

e) Engineering geological conditions at the openings of tunnels as well as the adverse geologic phenomena which might influence the stability of the tunnel;

8.2.2 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.

a) The scope of the geological surveying and mapping should include 1 km area on both sides of the axis. Themeasuring scale for the water delivery route 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 can 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 can be set if necessary and the drilling depth shall be less than 10m below the tunnel bottom elevation;

d) Pump-in (injection) tests shall be performed for the drilled holes; pumping tests shall be carried out in the sections where the confined water is distributed;

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 During the preliminary level engineering geological investigation for the water delivery route in the feasibility study stage, the investigation of the geological conditions including the topography and geomorphology, formation lithology, geologic structure and hydrological geology, as well as the main engineering geological problems will be performed and their influences on all kinds of water conveyance structures will be preliminarily assessed so as to perform the geological authentication for selecting the appropriate route. It is necessary to preliminarily investigate the following contents:

a) The topographic and geomorphological features and physical and geological phenomena of the water conveyance 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) 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 which might influence the stability of the tunnel;

f)I f the tunnel runs through the coal-bearing stratum, and the oil shale and bituminous stratum, it is necessary to perform a study on the harmful gases; for the intrusive body in large scale, it is necessary to test and study the radioactive elements;

g) The physical and mechanical parameters of various rock and soil bodies are proposed; preliminarily classify the tunnel surrounding rocks. For details, see Appendix B.

8.3.2 When selecting working methods and arranging investigation work, it is necessary to meet the following requirements:

a) Focus on data collection and geological surveying and mapping. The scope of the geological surveying and mapping should include 1km area on both sides of the axis. The measuring scale for the water delivery route should be 1:10 000 to 1:5 000; Specific geological surveying and mapping shall be performed forthe channel section beside the hill as well as the high fill, deep excavation and the channel with complexengineering geological conditions; the mapping scale should be 1:2 000 to 1:1 000. The geologicalsurveying and mapping shall be performed in the entrance/exit of the tunnel, the shallowly buried sectionbeside the hill, the section crossing ditches and other sections with complex engineering geologicalconditions at the mapping scale of 1:2 000 to 1:1 000;

b) For the channels, the geophysical prospecting profile shall be arranged along the centreline; 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 shall be arranged along the centreline of the channel project, and the exploration points shall be arranged in the sections across the rivers and ditches and with complex engineering geological conditions, and the spacing should not be more than 1 000 m; the prospecting should be realized mainly by Test Pits and Trenches, and drillingexploration; the drilling exploration depth should be less than 10m below the design floor elevation;

d) Geological surveying and mapping should be the main method 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 in the tunnel section;

e) The drilling should be arranged for the entrance/exit of the tunnel, shallowly buried section beside the hill, section crossing ditches and other sections with complex engineering geological conditions; the drilling depth shall be less than 10m below the tunnel bottom elevation;

f)P ump-in (injection) tests shall be performed for drilled holes; pumping tests shall be carried out in the sections where the confined water is distributed;

g) The geological parameters may be determined by field and laboratory tests, and in combination 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 two different design stages: 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, it is necessary to investigate the engineering geological conditions and the main engineering geological problems in the power plant area. It is necessary to particularly investigate the following 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 plant.

9.2.2 The engineering geological investigation mainly involves collecting regional geological data and surveying and mapping for geology. A little geophysical prospecting and drilling exploration can 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 map of the reservoir area may be adopted for the surveying and mapping for geology, while the engineering geological map of the dam area may not be necessary; when the engineering geological condition is relatively complex, it is suggested to draw a 1:2 000 to 1:1 000 scale engineeringgeological map;

b) Arrangement of the investigation work: Usually the 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 usually are applied for the plant area and behind the plant area;

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 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 need to be preliminarily ascertained:

a) Morphological characteristics of the topography and geomorphology of each selected plant area;

b) Formation lithology, as well as cause, composition material and distribution in the each selected plant area;

c) Main geologic structure of each selected plant area, 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 in the each selected plant area;

e) The stability of the slope at the back of the plant in the each selected plant area;

f) Evaluate the hydrogeological conditions of each selected plant area and especially the permeability of the rock and soil in the foundation pit of the powerhouse, the seepage and seepage deformation of the pressure forebay, and the corrosiveness of the surface water and groundwater to the concrete and steel structures.

9.3.2 When selecting the working methods and arranging the investigation work, it is necessary to meet the following requirements:

a) In the plant area, the engineering surveying and mapping may be performed in combination with the engineering geological map of the dam area, but excluding the engineering geological map for the plant area to be drawn separately in the dam area. The measuring scale for the geological surveying and mapping should be1: 2 000 to 1: 1 000; the mapping scope shall include the alternative schemes of the surge shaft, penstock, plant, switchyard and other civil 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 overburden, 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 a group of surface water samples and a group of groundwater samples shall be taken for water quality analysis to assess its corrosivity to the concrete and steel structure;

g) Sampling, the standard penetration test or the conical dynamic penetration test should be carried out according to different soil properties when the foundation of the pressure forebay, penstock, powerhouse and switchyard is the overburden layer, and the effective number of sampling groups in each soil layer should not be less than 6.

h) The geological parameters shall be determined according to field and laboratory tests, and in combination with engineering geological analogy and experience-based judgment.

# 10 Geological investigation of natural construction materials

## 10.1 General provisions

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

## 10.2 Pre-feasibility study stage

10.2.1 In the pre-feasibility study stage, it is necessary to carry out a general survey for the natural construction materials required by the project.

10.2.2 The geological investigation around the project area shall be carried out on the basis of collecting, analysing and using the relevant data in the region. The borrow (quarry) area for natural construction material shall be selected with full consideration given to the safety and environmental factors; it is necessary to preliminarily judge whether its quality and reserves could satisfy the engineering demands by means of engineering geological analogy and experience-based judgment.

## 10.3 Feasibility study stage

10.3.1 In the feasibility study stage, an inspection should be carried out on natural construction materials such as stone, sand and gravel, and the soil materials required for project construction. The investigation shall be performed from the near to the distant, to perform qualitative and quantitative analyses of the natural construction materials, and to analyse the impacts of natural construction material mining on the environment with full consideration given to the safety and environmental factors.

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

10.3.3 Investigated reserves of various natural construction materials should be 2 times the design requirements.

10.3.4 The selected block stones shall be judged by experience according to its place of origin. If the strength and quality of the rocks highly exceed the design requirements, it is allowed to determine the physico-mechanical indices of the rocks by engineering geological analogy and experience-based judgment, and 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 interval between holes should be less than 100 m; the holedepth 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 shall be arranged for the sand-gravel quarry area according to the following requirements:

a) With regard to the quarry area which has widely distributed and stable sand-gravel, and has a thick productive layer of it, 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 1m below the maximum excavation depth.

10.3.8 Samples shall be taken from the Test Pits in the sand-gravel quarry area, to calculate the reserves of sand-gravel materials of various grades. The organic matter and sediment percentage of sand material shall be measured.

10.3.9 The exploratory points of the soil borrow area should be arranged according to the following requirements:

a) With regard to the soil borrow area with a large area, flat terrain, a thick productive layer and a one fold soil layer, the spacing between exploratory points shall be 100 m to 200 m;

b) With regard to the soil borrow area 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 every borrow area, and the well depth shall be 0.5m to 1m below the maximum excavation depth.

10.3.10 The borrow area for soil shall be sampled for routine testing and compaction testing; the routine test items mainly include the natural water content, density, specific gravity, liquid limit, plastic limit, particle size analysis, organic content and water-soluble salt content.

10.3.11 To learn about the compactibility of the soil material, it is necessary to perform compaction testing to determine the relationship between the density and the water content of the soil material; for some expansive soils, it is also necessary to measure its expansibility, chemical components and clay mineral.

10.3.12 It is necessary to investigate the mining conditions and the environmental geological impact, mainly including the distance between the borrow (quarry) area and the proposed project area, the existing access road, groundwater level and water yield property of the borrow (quarry) area. The damage to vegetation after the borrowing of materials as well as the influence on the geological environment, and the prediction of its development trend shall be carried out while suggestions on treatment and repairs 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 rocks (Rb> 60MPa) | | | |
| I | $A_I$: 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. | 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. | Rb>90 MPa<br>Vp>5000 m/s<br>RQD>85%<br>Kv>0.85 |
| II | $A_{II}$: 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. | 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. | Rb>60 MPa<br>Vp>4 500 m/s<br>RQD>70%<br>Kv>0.75 |
| III | $A_{III1}$: 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. | 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. | Rb>60MPa<br>Vp=4000~4500m/s<br>RQD=40%~70%<br>Kv=0.55~0.75 |
| | $A_{III2}$: 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. | Rb>60MPa<br>Vp=3000~4500m/s<br>RQD=20%~40%<br>Kv=0.35~0.55 |

| Type | Rock mass characteristics | Rock mass engineering property evaluation | Rock mass main characteristic value |
|---|---|---|---|
| A hard rocks (Rb> 60MPa) | | | |
| 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. | Rb>60 MPa<br>Vp=2500~3500m/s<br>RQD=20%~40%<br>Kv=0.35~0.55 |
| | $A_{IV2}$: 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. | Rb>60 MPa<br>Vp<2500m/s<br>RQD<20%<br>Kv<0.35 |
| IV | 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 - Engineering geologic classification of the dam foundation rock mass (continued)**

| Type | Rock mass characteristics | Rock mass engineering property evaluation | Rock mass main characteristic value |
|---|---|---|---|
| B medium-hard rocks (Rb=30~60MPa) | | | |
| I | — | — | — |
| II | $B_{II}$: The rock mass structure of BII is similar to that of AI. | 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<br>Vp=4000~4500m/s<br>RQD>70%Kv>0.75 |
| III | $B_{III1}$: The rock mass structure of BIII1 is similar to that of AII. | 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<br>Vp=3500~4000m/s<br>RQD=40%~70%<br>Kv=0.55~0.75 |
| | $_{BIII2}$: 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<br>Vp=3000~3500m/s<br>RQD=20%~40%<br>Kv=0.35~0.55 |

| Type | Rock mass characteristics | Rock mass engineering property evaluation | Rock mass main characteristic value |
|---|---|---|---|
| B medium-hard rocks (Rb=30~60MPa) | | | |
| IV | $B_{IV1}$: 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 AIV1. | Rb=30 ~ 60 MPa<br>Vp=2000~3000m/s<br>RQD=20%~40%<br>Kv<0.35 |
| | $B_{IV1}$: 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 AIV2. | Rb=30 ~ 60 MPa<br>Vp<2 000m/s<br>RQD<20%<br>Kv<0.35 |
| V | Same as that of Av. | Same as that of Av. | — |
| C Soft rock (Rb<30MPa) | | | |
| I | — | — | — |
| II | — | — | — |
| III | $C_{III}$: With the rock strength of 15MPa 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. | Rb<30 MPa<br>Vp=2500~3500m/s<br>RQD>50%Kv>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. | Rb<30 MPa<br>Vp<2500m/s<br>RQD<50%<br>Kv<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°. | | |

| 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 | 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°. | 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. | Combined bolting and shotcrete or shotcrete-bolting-mesh; vault system anchor rod |
| | | 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°. | | |
| | | 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°. | | |
| | | 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°. | | |

**Table B.1 - (continued) Surrounding rock engineering geologic classification**

| Surrounding rock type | Surrounding rock stability | Main engineering geological characteristics of the surrounding rocks | Unlined tunnel self-stabilization and deformation | Support type |
|---|---|---|---|---|
| IV | Stable | 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°.<br>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°.<br>Relatively-soft rocks or soft rocks are mainly weakly weathered ones. With the joint fissure relatively developed, the rock formation usually dislocates. Therefore, unfavourable combinations of weak surfaces and other structural surfaces are formed. The ground water moves slightly. The intersection angle between the tunnel line and the rock formation strike is greater than 30°. | 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. | 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. |
| V | Extremely unstable | 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.<br>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°.<br>Completely weathered rocks in the loose gravel-soil uneven loose structure. The ground water moves from medium to strong. | 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. | With poor excavation conditions, closely followed or advanced support, or full cross-section lining are required. |

# 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 0.05mm | Clay - silt |
| Low permeability | Lower | $10^{-4}\leq K<10^{-3}$ | $1\leq q<3$ | Including rock mass with cracks with equivalent opening 0.05mm to 0.1mm | 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 0.1mm to 0.5mm | Sand and gravel |
| High permeability | | $10^{-1}\leq K<1$ | $100\leq q$ | Including rock mass with cracks with equivalent opening 0.5mm to 2.5mm | Gravel - grit, grait |
| 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 θ | Slight slope | $\theta \leq 10°$ |
| | Slope | $10° < \theta \leq 30°$ |
| | Steep slope | $30° < \theta \leq 45°$ |
| | Sharp slope | $45° < \theta \leq 65°$ |
| | Extremely sharp slope | $65° < \theta \leq 90°$ |
| | Adverse slope | $90° < \theta$ |
| 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(m3) | 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 | 1. Joint fissure cutting and filling<br>2. Weathering characteristics | Looseness, cracks and deformation are the main modes with unloading cracks regularly occurred and partial crumbling occurred some times | 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 conveyance structures on the slope. | 1. Anchor rock mass that may have partial crumbling.<br>2. Slope drainage shall be properly arranged to prevent partial instability of the slope caused by water filling through cracks. |
| 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. | 1. Stratum angle<br>2. Rock formation surface shear strength<br>3. Joint development characteristics and filling | 1. Stretching sliding<br>2. Upper deformation or creep deformation due to soft slope root<br>3. Creeping along the soft rock strata | 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. | 1. Prevention of bedding slip for soft rock strata<br>2. Partial anchoring<br>3. Soft rock strata removal and backfill<br>4. Supporting engineering used for slip prevention<br>5. Water drainage |
| 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. | 1. Development and filling of joint fissure, especially joint development<br>2. Soft rock strata development<br>3. Impacts of crack water<br>4. Vibration | 1. Surface rock formation creeps, deforms and dumps.<br>2. Partial crumbling<br>3. Slip | 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. | 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.<br>2. Check the joint distribution characteristics and analyse combined structural surfaces with no unfavourable skid resistance factors. |

| 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 | 1. Joint fissure distribution characteristics<br>2. Distribution of lithology and soft rock strata<br>3. Underground water crustal stress and weathering characteristics | 1. Creep tilting and loose deformation<br>2. Deformation occurs in the upper part when the soft rock strata are located at the slope foot.<br>3. Partial crumbling and slip | 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. | 1. Check joint fissure distribution characteristics and properly cut the slope to prevent partial crumbling and slip.<br>2. Partial anchoring |
| Slope with rocks in diagonal formation | Bedded rocks with the rock direction and the slope surface forming an angle | Joint fissure development | 1. Crumbling<br>2. Sphenoid slide | 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 | 1. Degree of rock body crushing<br>2. Joint fissure development<br>3. Impacts of crack water<br>4. Vibration | 1. Crumbling<br>2. Collapse | Partial collapse can easily occur, affecting the civil structure safety; water permeable, unfavourable to dam shoulder stability and load bearing | 1. Properly clean and select a stable slope foot.<br>2. Anchor ejection protection on the surface<br>3. Water drainage |

## Table D.3 - Soil slope classification

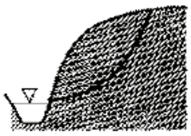
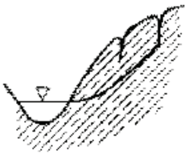
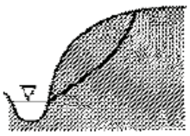
| Slope type | Main characteristic | Main factors that affect the stability | Main possible deformation and broken modes | Relationship with the engineering | Principle of treatment and methods and suggestions |
|---|---|---|---|---|---|
| Clay slope | It mainly consists of clay and is hard when dry and crumbles after extension when wet. | 1. Mineral composition, especially content of hydrophilic, expansion and soluble minerals.<br>2. Effects of water<br>3. Effects of freeze thawing | 1. Clay with expansive hydrophilic mineral can easily cause a landslide; high slope can cause a high-speed landslide due to slope foot creeping.<br>2. Peeling off caused by freeze thawing<br>3. Collapse | 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. | 1. Waterproof and water draining<br>2. Cut slope presser foot<br>3. Slope with freeze thawing peeling: grass planting or protection coverage, slope water draining and slope dry |
| 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. | 1. Granular component and uniformity coefficient<br>2. Contains moisture<br>3. Vibration<br>4. Effects of external water and underground water<br>5. Compaction rate | 1. Slope with saturated sandy soil can easily have liquefaction landslide under the effect of the vibratory force.<br>2. Piping and flowing soil<br>3. Collapse and peeling off | 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. | 1. Water drainage<br>2. Cut slope presser foot<br>3. Take vibro-compaction and closing measures in advance and pay attention to drainage. |
| 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. | 1. Crumbling<br>2. Tension crack<br>3. Collapse<br>4. The high slope may have a high-speed landslide. | 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. | 1. Waterproof and drainage shall prevent water conveyance structure from leakage as far as possible.<br>2. Reasonable slope cutting<br>3. Monitor and forest the sloughing bank and ancient landslide. |

| 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. | 1. Soft soil (characteristics of low shearing strength, high compressibility and plastic flow deformation)<br>2. Exogenous process and vibration | 1. Landslide<br>2. Plastic flow deformation<br>3. Collapses; it is difficult to form a slope; | The channel cannot form when going through the soft soil area due to plastic flow deformation; when the slope has soft oil at its foot, the slope may collapse due to flowing deformation. | 1. Thorough removal<br>2. Avoid<br>3. Pressure back filling<br>4. Water drainage solidification |
| 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. | 1. Dry and wet climatic changes<br>2. Effects of water | 1. Shallow landslide<br>2. Superficial layer disintegration | Continuous slide or collapse caused by natural conditions changes and surface layer expansion and disintegration after slope excavation | 1. Do not change the containing water of the soil as far as possible.<br>2. The protective layer is reserved. Cover it soon after excavation for moisture preservation.<br>3. Select a stable slope angle.<br>4. Drainage reinforcing and protection closure |
| 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. | 1. Environmental water with low saltiness<br>2. Water solution in holes with high sodium content and high alkalinity medium<br>3. Naked soil in contact with water | 1. Washout holes and passages<br>2. Piping, collapse and corrosion holes<br>3. Collapse, crumble and landslide | Dam and channel slope has random deformation and fracture or potential crisis during construction and operation. | 1. It should not be used as foundation or construction materials.<br>2. Totally closed, separating water from soil<br>3. Loaded filter setting<br>4. Soil character improvement<br>5. Engineering environment water improvement for saltiness increase |

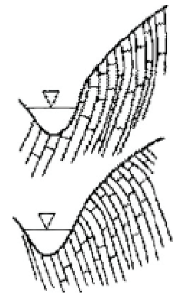
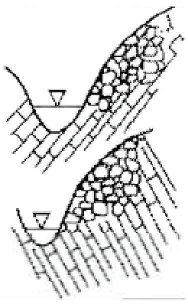
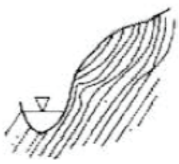
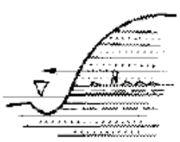
| Slope type | Main characteristic | Main factors that affect the stability | Main possible deformation and broken modes | Relationship with the engineering | Principle of treatment and methods and suggestions |
|---|---|---|---|---|---|
| Gravelly soil slope | This slope consists of hard rock fragments and sandy soil particles or gravelly soil, and shows up in accumulation structure, slide rock mixed structure and multiple structure. | 1. Clay particle content and distribution characteristics<br>2. Slope water containing<br>3. Subterranean occurrence | 1. Soil landslide<br>2. Collapse | 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. | 1. Properly select a stable slope angle.<br>2. Slope drainage strengthening prevents water injection into the slope.<br>3. Monitor the key sections of the reservoir bank in the storage period. |
| 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. | 1.Subterranean occurrence<br>2. Soil layer being soaked by water and with water leaking into the body. | 1. The soil layer slides along subterranean.<br>2. The soil layer partially clamps.<br>3. The upper rock mass creeps or staggers along the soil layer. | 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. | 1. Properly select a stable slope angle.<br>2. Slope drainage strengthening prevents water injection into the slope.<br>3. Monitor the key sections of the reservoir bank during the storage period. |

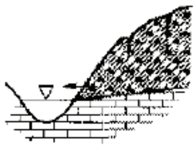
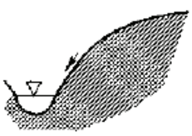
**Table D.4 - Deformed slope classification (by deformation characteristics)**

| 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 | Tension crack deformation 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. | 1. The soft layer at the slope foot is further softened or washed<br>2. Vibration<br>3. Rainstorm and impeded drainage<br>4. Stress relief | 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. | 1. Prevent the situation where the soft layer at the slope foot is further softened or manually damaged.<br>2. Control the explosion scale and method.<br>3. Consolidation grouting or anchoring<br>4. Explosion load shedding if necessary |

| 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 | Soil landslide | Clay landslide |  | The clay is hard when dry and clamps when wet. Drainage difficulty, continuous rainfall or humidifying can reduce the strength and easily lead to a slope slide. | 1. Effects of water: rainstorm soaking, manual water injection and drainage difficulty<br>2. Vibration: earthquake and exposure<br>3. Improper excavation mode: foot cutting, head loading and landslide are excavation from bottom to upper are inappropriate for civil structure layout. | 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. | 1. Pay attention to the excavation mode and procedure.<br>2. Drainage of the slope surface and the slope body<br>3. Supporting structure, slide-resistant pile, etc. |
| | | Loess 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. | | | |
| | | 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. | | | |
| | | Gravelly 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. | | | |

| 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 | Rock slope | Homogeneous 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. | 1. Rock strength<br>2. Effects of water<br>3. Slope grade and height | The landslide is on a large-scale, may reoccur after conditions deteriorate, and is unsuitable for the layout of civil structures. | 1. Avoid<br>2. Removal or partial removal<br>3. Water drainage |
| | | Bedding landslide |  | Landslide generally occurs along the rock formation, which is mainly controlled by rock formation in status. | 1. Soft rock strata or bedding shearing strength<br>2. Erosion cutting and improper excavation | If it is used as civil structure slope, it will affect the civil structure security. It is unsuitable as a channel slope. | 1. Removal or partial removal<br>2. Water drainage<br>3. Supporting or anchoring when the scale is small. |
| | | In sequent landslide |  | The sliding surface cuts off the layer, so the slip mass status is controlled by several groups of joint fissures. | 1. Joint cutting<br>2. Rock mass strength<br>3. Effects of water<br>4. Gently inclined structural surface and soft rock strata | It is not suitable for being slopes of channels or other civil structures. | 1. Removal or partial removal<br>2. Water drainage<br>3. Supporting or anchoring when on a small scale. |
| | | 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. | 1. Joint fissure cutting<br>2. Rock mass strength<br>3. Effects of water | Water permeability is not highly conducive to the seepage-proofing of the dam shoulder. It is unsuitable as a channel slope. | 1. Slope cutting and clearing<br>2. Water drainage<br>3. Supporting when on a small scale. |

| 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 | Rock slope | Dump creep deformation slope |  | 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 stratums; dump amplitude reduces gradually by depth; reverse banks occur sometimes on the slope surface. | 1. Excavation angle<br>2. Vibration<br>3. Water filling and drainage difficulty | Unfavourable anti-permeability; large subsidence deformation; unfavourable to engineering loading bearing; continuous collapse caused by excavation angle | 1. Removal from top to bottom; the excavation angle should not be greater than the natural slope angle.<br>2. Seepage-proofing for drainage of the slope surface and the slope body<br>3. If the deformation is fast, an excavation protective layer shall be reserved. |
| | | Loose creep deformation slope |  | 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. | 1. Excavation angle<br>2. Vibration<br>3. Water filling and drainage difficulty | It is unfavourable to seepage-proofing and bearing; the excavation angle often causes continuous collapse. The large-scale loosened bodes 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. | 1. Keep the original status and naturally stable.<br>2. Drainage of the slope surface and the slope body<br>3. Removal from top to bottom; the excavation angle should not be greater than the natural slope angle. |
| | | 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 stratums occurs with non-obvious separation fractures. | 1. Effects of rock flowing deformation<br>2. Effects of water<br>3. Vibration<br>4. Excavation unloading and improper excavation mode | Partial bedding sliding or slow distortion affects the civil structure security. Except surface layers, water permeability is not high generally. | 1. Slope cutting for removal; the excavation angle shall be appropriate.<br>2. Reserving excavation protection layer<br>3. Partial anchoring |
| | | Plastic flow creep deformation slope |  | Brittle rocks move slowly along the lower plastic soft rock strata. | 1. Further argillization occurs to the ductile bed under the effects of water.<br>2. Flowing deformation effect on the soft formation. | 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. | 1. Drainage of the slope surface and the slope body<br>2. Partial anchoring<br>3. Remove the upper rock mass along the plastic flow formation. |

| 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 | Soil slope | 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. | 1. Effects of water<br>2. Soil at the slope foot or the broken soil body may have flowing deformation when wet.<br>3. Slope soil flowing deformation under the effects of the long-term action of gravity | Landslide may occur when the slope encounters water or vibration. This slope shall not be used as the channel or civil structure slope. | 1. Excavation by the stable slope foot<br>2. Clear<br>3. Drainage of the slope surface and the slope body |
| Collapse deformation | Rock (soil) slope | Crumble deformation 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. | 1. Weathering and freezing expansion<br>2. Rainstorm and impeded drainage<br>3. Vibration<br>4. Slope foot water erosion softening | 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. | 1. Remove the dangerous rocks to protect the civil structure.<br>2. Partial anchoring and supporting<br>3. When the foundation is built using debris, special seepage-proofing and reinforcement treatment is required. |
| Collapse deformation | Rock (soil) slope | Collapse deformation 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. | 1. Plastic flow formation creep deformation<br>2. Rainstorm and impeded drainage<br>3. Vibration<br>4. Unfavourable lithological association and structural surface | Loose debris with high water permeability can easily sink or deform unevenly. It may partially continue to slide after being soaked. | 1. Slope surface seepage-proofing and slope body drainage<br>2. Clear<br>3. Partial supporting |
| Peeling deformation | Rock (soil) slope | Peeling deformation 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. | 1. Effects of freeze thawing<br>2. Dry-wet effects<br>3. Weathering | Channel or other engineering slopes are loose on the surfaces and collapse, increasing the difficulty maintaining. | 1. Grass planting slope coverage for protection<br>2. Water drainage<br>3. The protective layer is reserved. |

# 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<br>Weak-corrosive<br>Moderate-corrosive<br>Strong-corrosive | pH>6.5<br>6.5≥pH>6.0<br>6.0≥pH>5.5<br>pH≤5.5 |
| Calcareous type | Corrosion $CO_2$ content (mg/L) | Non-corrosive<br>Weak-corrosive<br>Moderate-corrosive<br>Strong-corrosive | $CO_2$ <15<br>15≤$CO_2$ <30<br>30≤$CO_2$ <60<br>$CO_2$ ≥60 |
| Bicarbonate type | $HCO_3$ Content (mmol/L) | Non-corrosive<br>Weak-corrosive<br>Moderate-corrosive<br>Strong-corrosive | $HCO_3$ >1.07<br>1.07≥$HCO_3$ >0.70<br>$HCO_3$ ≤0.70<br>– |
| Magnesium | $Mg^{2+}$ Content (mg/L) | Non-corrosive<br>Weak-corrosive<br>Moderate-corrosive<br>Strong-corrosive | $Mg^{2+}$ <1 000<br>1000≤$Mg^{2+}$ +<1500<br>1500≤$Mg^{2+}$ <2000<br>$Mg^{2+}$ +≥2000 |
| Sulphate | $Mg_4^{2+}$ Content (mg/L) | Non-corrosive<br>Weak-corrosive<br>Moderate-corrosive<br>Strong-corrosive | $Mg_4^{2+}$ <250<br>250≤$Mg_4^{2+}$ <400<br>400≤$Mg_4^{2+}$ <500<br>$Mg_4^{2+}$ ≥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<br>Moderate-corrosive<br>Strong-corrosive | 100~500<br>500~5 000<br>>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 $Cl^-+Cl^-+SO_4^{2+}$content (mg/L) | Weak-corrosive<br>Moderate-corrosive<br>Strong-corrosive | pH value: 3-11, ($Cl^-+Cl^-+SO_4^{2+}$)<500<br>pH value: 3-11, ($Cl^-+Cl^-+SO_4^{2+}$) ≥500<br>pH<3, ($Cl^-+Cl^-+SO_4^{2+}$) any concentration |

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