INTERNATIONAL WORKSHOP AGREEMENT

IWA 33-3

First edition
2021-03

Technical guidelines for the development of small hydropower plants —

Part 3: Design principles and requirements

Reference number
IWA 33-3:2021(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was 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 this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

International Workshop Agreement IWA 33 was approved at a workshop hosted by the Standardization Administration of China (SAC) and Austrian Standards International (ASI), in association with the International Center on Small Hydro Power (ICSHP), held virtually from 19th to 23rd October, 2020.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

A list of all parts in the IWA 33 series can be found on the ISO website.

Introduction

Small hydropower (SHP) is well recognized as an important renewable energy solution to the challenge of increasing access to electricity in remote rural areas. However, while most countries in Europe, North and South America, China and India 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 best practices or standards for SHP development.

The technical guidelines for the development of small hydropower plants contained in this document 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 this document to support their current policy, technology and legislation. Countries that have limited institutional and technical capacities will be able to enhance their knowledge base in developing SHP plants on rivers/streams and existing water resource structures outlets such as dams, barrages, navigation lock, canal falls, outfalls and flowing water (kinetic flow), including renovating/upgrading the old SHP plants, thereby attracting more investment in SHP projects, encouraging favourable policies and subsequently assisting in economic development at a national level. This document will be valuable for all countries, but also allow for the sharing of experience and best practices between countries.

This document is the result of a collaborative effort between the United Nations Industrial Development Organization (UNIDO) and the International Network on Small Hydro Power (INSHP). About 80 international experts and 40 international agencies were involved in this document's preparation and peer review. This document can be used as the principles and basis for the planning, design, construction and management of SHP plants up to 30 MWe.

Technical guidelines for the development of small hydropower plants —

Part 3: Design principles and requirements

1 Scope

This document specifies the general principles and basic requirements of design for small hydropower (SHP) projects up to 30 MWe, mainly including hydrology, geology, energy calculations, project layout, hydraulics, electromechanical equipment selection, construction planning, project cost estimates, economic appraisal, social and environmental assessments.

Application of this document is intended to be site specific, with the principles and requirements of design applied in accordance with the needs of proposed hydropower plant.

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.

IWA 33-1, *Technical guidelines for the development of small hydropower plants — Part 1: Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IWA 33-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Hydrology

4.1 Basic data

4.1.1 The basic data include hydrometeorological data, river basin physiographic characteristics data, information about the human activities impact, hydrological computation results of the basin and nearby areas and the other relevant data. The changes in water resources management that occur upstream of a hydropower plant during its long lifespan will alter the runoff regime. Thus, the present and foreseeable needs of the population living on both sides of the river shall be taken into account for water supply, irrigation, industrial, ecology and recreation purposes.

4.1.2 The data series upon which hydrological computation is based shall be checked for reliability, consistency and representativeness.

4.1.3 The investigation of historical floods and dry seasons shall be carried out for the regions with insufficient or no data; if the conditions permit, observation and survey of water level, flow and sediment shall be carried out, and a long-term water regime monitoring and reporting system may be set up if necessary.

4.1.4 Considering the impacts of climate change on the evolution of river flows is necessary as the SHP plants normally are on smaller catchment not having much channel storage becoming more vulnerable for changes in flows in terms of discharge, intensity, spatial and temporal distribution variation. These shall be studied for the basin from the simulation with hydrological models. The entire hydrograph set shall be considered in planning and in fixing the capacity. Results of these specialized study should be used for finalising the runoff data.

4.2 Runoff (discharge)

4.2.1 According to the design requirement and data availability, all or part of the following design runoff results shall be provided:

a) historic daily runoff series measured or simulated at the site of the proposed hydropower plant;

b) annual mean runoff as well as the annual runoff, runoff in flood season, runoff during dry season with the designated frequency (return period) or the design representative years;

c) the annual distribution of the runoff in the design representative years.

4.2.2 According to data availabilities, the design runoff should be calculated by the following method.

a) When sufficient measured runoff data are available on the project site, the frequency analysis shall be used.

b) When there is a runoff gauging station in the downstream/upstream of the project site, in the river basin, adjacent basin or nearby basin with similar homogeneous meteorological and hydrological conditions, the hydrologic analogy method should be adopted.

c) If measured runoff data are not available, the rainfall-runoff relationship or model method may be adopted according to the precipitation data and physiographic characteristics of the watershed.

d) When the runoff data are not available, it may be estimated by relevant hydrological manual and calculated on the basis of comprehensive analysis of regional results, taking into account variations in topography, geology, vegetation cover and land use.

4.2.3 The runoff frequency computation shall meet the following requirements.

a) In the n-term consecutive runoff series, the empirical frequency P_m of term m in descending order, shall be computed using Formula (1):

$$P_m = \frac{m}{n+1} \times 100\% \qquad (1)$$

where

n is the number of terms of the observation series;

m is the order in the observation series;

P_m is the m^{th} empirical frequency.

b) The runoff frequency curve usually uses the Pearson curve III, while other types adaptive to the local conditions may also be selected according to the geological, meteorological and hydrological conditions of the project location.

4.2.4 The consecutive runoff series for the frequency analysis and computation should meet the following requirements.

a) Long time runoff series of up to 20 years or more in principle may be used. However, shorter time series of 10 to 20 years may also be used appropriately when limited data are available. The measured data shall be used even if the stream has been modified in accordance with the requirements of 4.2.

b) When the measured runoff data are insufficient, the interpolation shall be adopted to extend the runoff series and then the frequency analysis shall be carried out.

c) The relevant parameters used for interpolating and/or extending the existing runoff series shall be measured within an appropriate period in a continuous or discontinuous way simultaneously. The extension amplitude of the relevant line shall not be more than 50 % of the measured variation amplitude. The correlation coefficient should be more than 0,8.

4.2.5 The annual distribution in the design representative year may be determined by using the homogeneous multiple adjustment method over the controlled annual water flow; when the measured runoff data are insufficient, the existing synthesis chart of runoff area may be used with caution.

4.2.6 The daily mean flow duration curve can be adopted with the following method according to the runoff data availabilities.

a) When sufficient runoff data are available, the daily mean flow ranking statistics of long series or the daily mean flow in the typical high-flow (up to 25 % dependable) year, median-flow (50 % dependable) year and low-flow (higher than 75 % dependable) year should be used.

b) When the measured runoff data are insufficient, the monthly average flow duration curve may be deduced first, and then converted to the daily average flow duration curve through comparative analysis of the daily and monthly average flow duration curves of the runoff gauging station or the regional synthesis.

4.2.7 When the low water runoff data are insufficient, the low-flow investigation may be performed, especially in the dry season.

4.2.8 When runoff is significantly affected by human activities, the same may be accounted for.

4.2.9 The design runoff shall account for the cases of the complex landform with extremely uneven or unstable river channels, and special geological conditions such as karst.

4.3 Flood

4.3.1 According to the data availability and the engineering design requirements, all or part of the following design flood results shall be provided:

a) annual maximum peak flow at design frequency;

b) staged maximum peak flow at design frequency;

c) annual and staged period flood at design frequency;

d) annual and staged design flood hydrograph at design frequency.

4.3.2 When sufficient measured flood data are available, frequency analysis and computation shall be carried out to deduce the design flood. The frequency curve shall be based on the most appropriate statistical distribution. When the frequency curve is deduced from the empirical frequency points, the statistical parameters should be estimated preliminarily by the mathematical expectation equation, and then determined after adjustment with the curve-fitting method. When the curve-fitting method is adopted, the relatively reliable big flood events shall be considered on the basis of the fitting point group trend.

4.3.3 When measured flood data are available, the design flood hydrograph shall be deduced by amplifying the typical flood hydrograph, and the large flood which can reflect the flood characteristics and is relatively adverse to the flood control of the project shall be selected as the typical flood.

4.3.4 When the design flood is deduced from the design storm, the regional synthesis results of the storm flood charts shall be used for the design of the rainfall pattern, runoff yield and runoff concentration parameters and the design flood hydrograph. Comprehensive selection shall be based on the analysis and synthesis according to the measured rainstorm flood data of the gauging station. Alternatively, the empirical equation of flood peak flow in this region may be used.

4.3.5 According to the catchment area of the site and the comprehensive analysis results of the measured storm flood data from the gauging station, the short-duration peak storm period controlled by the same frequency in the design rain pattern shall be reasonably determined.

4.3.6 When the measured storm flood data are insufficient or the design basin storm flood parameters cannot be determined, the relation curve of the "measured and investigated big flood peak flow modular (M) - catchment area (F) - recurrence interval (N)" at the gauging stations in the region or the nearby areas may be ascertained, and the design flood may be estimated with the regional synthetic method.

4.3.7 Close attention shall be paid to investigation and review of historical floods and the following requirements shall be met:

a) reliable or relatively reliable data on major or relatively major historical floods shall be used in the frequency analysis and computation, or to verify design flood results determined by regional synthesis analysis, or to assist the derivation of the stage-discharge relation curve.

b) when data are limited, the design flood may be estimated according to historical flood results.

4.3.8 The design flood of cascade hydropower plants shall be calculated according to the layout of cascade projects, the discharge or diversion modes of the plant and the intervening catchment areas between two plants.

4.3.9 When computing the design flood by construction stages, the design requirements of the engineering construction stages shall be considered, and the variation rules and characteristics of flood causes shall be basically compiled within the period from the beginning to the end.

4.4 Stage-discharge relation curve

4.4.1 The stage-discharge relation curve between the upstream inlet section and the downstream tail water section of the hydropower plant shall be drawn up.

4.4.2 When there are gauging stations near the upstream/downstream areas of the project site, the stage-discharge relationship at the design cross-section may be obtained after the water level is corrected through water level correlation or investigation and measurements.

4.4.3 The high-water level extension of the stage-discharge relationship may be calculated by slope method and determined by the comprehensive analysis of flood investigation.

4.4.4 When there is no gauging station in the river reach of the project site, the stage-discharge relationship shall be determined with the single-section slope method according to longitudinal profile of the river reach and the cross-section profile, and with reference to the average bed slope of the main channel/river as well as the water surface slope and its estimated flow during floods and dry season.

4.5 Sediment, evaporation, ice regime and others

4.5.1 With regard to the location of the project on the river carrying significant sediment or carrying more sediment during the flood season, all or part of the following sediment computation results shall be provided according to the data availability and the engineering design requirements:

a) annual average suspended sediment and sediment runoff ratio;

b) monthly average suspended sediment at the annual maximum cross-section and the month of occurrence;

c) annual average suspended sediment size distribution or average and maximum particle diameter;

d) results of bed load sediment in the flood season [if conditions permit, the Sediment Rating Curves (Discharge vs Sediment Concentration) may also be developed for analysis].

4.5.2 The suspended sediment may be computed with the following method.

a) When there is a sediment gauging station in the basin of the site, the sediment yield modulus of the gauging station should be used.

b) When there is no sediment gauging station in the basin of the site, the sediment yield modulus may be used directly if their climatic conditions and underlying surface conditions are similar, otherwise they may be used after being corrected.

c) When the above data are not available, the existing regional synthesis diagrams of the sediment may be used; the sediment may be measured temporarily if necessary.

4.5.3 Bed load sediment may be computed with the suspended and bed load ratio.

4.5.4 For a reservoir-based hydropower plant, it is advisable to calculate the annual average water surface evaporation rate and its annual distribution according to the data from the evaporation measuring station in the basin or the regional synthesis diagrams of the evaporation rate in basin with similar hydrometeorological conditions.

4.5.5 For the hydrological analysis and computation in cold regions, the following ice regime at the plant site shall be provided according to the statistical data of local hydrological and meteorological characteristics:

a) river condition when freezing and unfreezing; occurrence of shore ice and floating ice and the freezing characteristics of the whole river;

b) earliest, latest and yearly average icing and melting dates;

c) ice thickness, ice clogging, ice wall, ice flakes and floating ice and their potential hazards during the freezing period.

4.6 Rationality check of the outcomes

4.6.1 The rationality check of the outcomes shall meet the following requirements.

a) The measured data and the analysis and computation results from all the relevant gauging stations shall be used.

b) The comparative analysis of the results of multiple methods in a single station and the study of the surface distribution of the results of multi-stations with the same methods shall be carried out.

c) The final results shall follow the principle of "based on one method, compared with multiple methods, by analysing comprehensively and selecting rationally".

4.6.2 The rationality check shall include the following main parameters or items:

a) annual mean runoff;

b) design peak flood and flood volume;

c) determination of the peak flood, and the roughness coefficient (n) in the computational equation of the slope method;

d) shape and characteristics of the flow-duration curve and the stage-discharge relation curve.

4.6.3 The rationality check of the design annual runoff and the design peak flood results shall meet the following requirements.

a) The computed results shall be consistent with the results of the regional synthesis contour map, the correlation curve or the empirical equation.

b) The distribution in the basin, region and along the upstream/downstream segment and the mainstream and tributaries shall basically be rational. The result shall basically be adaptive to the spatial variation in the precipitation.

c) If there is a big difference in the computed results, or unreasonable, or there is a big difference with the spatial variation of the precipitation, the causes shall be found out in time and re-analysed/computed if necessary.

4.6.4 The rationality check of the flow duration curve and the stage-discharge relation curve shall include the following contents:

a) the relationship between the flow duration curves as well as the influence of flow variation amplitude and base flow on the curve shape;

b) the relationship between the cross-section feature and the stage-discharge relation curve.

5 Engineering geology

5.1 General provisions

5.1.1 The engineering geological investigations shall include the following aspects:

a) regional geological conditions;

b) basic geological conditions and major engineering geological issues of the project area;

c) hydro-geological condition and assessment of aggressiveness of water;

d) availability, distribution, quantity and quality of natural construction materials.

5.1.2 The investigation shall be carried out in stages in accordance with planning and design stages.

5.1.3 The existing topographic and geological data shall be collected. According to the characteristics of the project, the complexity of the topographic and geological conditions and the requirements of the investigation extent in each stage, a variety of investigation methods shall be applied. Appropriate geological mapping, geophysical prospecting, drilling, pit exploration and laboratory tests shall be conducted, supplemented by adit exploration and in-situ field test depending on the situation.

5.1.4 The physical-mechanical parameters of foundation materials can be determined by engineering geological analogy and experience-based judgment; laboratory and field tests shall be performed if necessary.

5.2 Regional geology

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

5.2.2 Under the topographic and geomorphic investigations, the topographic and geomorphic characteristics of the region, especially the development situation and scope of the terrace, and the karst development characteristics in the karst area shall be studied.

5.2.3 Under geologic structure investigation, the strength and permeability of the structure, the distribution range, formation age and petrographic characteristics of various types of rocks shall be studied.

5.2.4 For the regional structural stability and seismic survey, the available regional geological data of the project area shall be studied to determine the geotectonic element of the project area and shall propose assessment opinions on the regional structural stability, judge the possibility of the proposed hydropower project site being impacted by active fault or seismic activities during expected project life, the impact intensity and its probability, and then propose appropriate ground motion parameters for a seismic design of the project. Special study shall be carried out on active faults which have influence on the project.

5.2.5 The geophysical conditions shall be assessed from the analysis of the basic geological data such as topography and geomorphology and geologic structure; to study its rule of occurrence and development, its causes, factors influencing its occurrence and development, its formation condition and mechanism, and its development process and stages; and to make correct assessments and formulate reasonable control measures.

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

5.3 Engineering geology of the reservoir area

5.3.1 The engineering geological investigation of the reservoir area shall comprise of the investigation of reservoir seepage, reservoir submergence, reservoir bank (slope/rim) stability, reservoir sedimentation and reservoir induced seismicity (RIS). In the case of an unstable slope, the hydrogeological conditions should also be studied evaluated.

5.3.2 The reservoir seepage investigation shall evaluate topography and geomorphology, lithology, geologic structure and hydrogeological conditions of reservoir seepage, analyse the form of reservoir seepage, evaluate the possible amount of reservoir seepage and propose measures to control reservoir seepage. The investigation of reservoir seepage shall include:

a) whether thin rim, low adjacent valley, permeable layer, fault fracture zone or ancient river course existed around the reservoir - the possibility and severity of seepage shall be assessed;

b) pattern of karst development in soluble rock zones of the reservoir, location and distribution of spring and groundwater area, distribution and permeability condition of relative confining beds, replenishment and discharge relationship between groundwater and river, etc., and to assess the probability of seepage, seepage routes, seepage amount, seepage features (conduits, solution cracks) and their impact on reservoir construction.

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

a) structure, thickness and composition of soil stratum at potential submerged areas, and the buried depth of underlying bedrock or opposite confining beds;

b) permeability of soil stratum, groundwater depth, replenishment and discharge conditions of groundwater, rising height of capillary water in soil stratum and critical depth of groundwater that causes immersion - the range of possible immersion shall be predicted and the possibility of swamping and salinization shall be analysed.

5.3.4 The reservoir bank stability investigation shall find out the engineering geological conditions with potential instability factors for the reservoir banks, such as a landslide and collapse, evaluate their influences, ascertain the engineering geological conditions of the soil bank slope and predict the extent of bank collapse. The investigation of reservoir bank stability shall include:

a) features and structural composition of rock (soil) mass of bank slope, distribution of soft soil stratum, incision condition of fracture structure, and attitude, extension and combination relationship of various controlling structures that are unfavourable to the stability of bank slope;

b) weathering of rocks, unloading status and deformation features of reservoir rock bank, and identification of the type, nature, scope and formation conditions of deformation;

c) distribution, scale and stability of landslides, slide mass and dangerous rocks at reservoir bank near the dam, and assessment of the impact of debris flow close to the dam;

d) distribution elevation and stable slope angle of various soil strata at bank areas that tend to collapse, stable slope angle of reservoir water wave zone, and prediction of the extent of bank collapse.

5.3.5 The investigation of the reservoir sedimentation shall ascertain the scour and erosion of the upstream river and gully of the reservoir, as well as the source, type, quantity and flow of the sediment in the reservoir area. The problem of the reservoir sedimentation shall be evaluated and the prevention and control measures shall be proposed.

5.4 Engineering geology of hydraulic structures

5.4.1 The engineering geological investigation of hydraulic structures shall cover the basic geological conditions such as topography, stratum lithology, geological structure, hydrogeology and major engineering geological conditions. The assessment of aggressiveness of water in the main hydraulic structures area shall be carried out.

5.4.2 The engineering geological investigation of earth-rock dam site shall include the following.

a) Stratigraphic texture, layering thickness and distribution features of the riverbed overburden and terrace deposit, and the distribution of the of sludge, fine sand layer, collapsible loess, suspended and solitary boulder layers in both the present and the past riverbeds. The bearing capacity, deformation, shear resistance, and seismic liquefaction of soil layer and other dam building conditions shall be evaluated. Based on these conditions depth at which the foundation shall be laid down need to be assessed.

b) The permeability coefficient, allowable permeability gradient and physical-mechanical parameters of rock (soil) shall be determined, and measures on treatment of unfavourable geological issues shall be put forward.

c) Distribution, width, filling condition of the fault fracture zone and zones with concentration fissures located at anti-seepage structures, and the seepage stability shall be evaluated.

d) Weathering, unloading thickness and properties of rock mass at dam foundation (abutment) shall be evaluated.

e) Distribution elevation of relative confining beds at dam foundation (or abutment) and depth of groundwater table on both banks, and the anti-seepage scope and depth of dam foundation (abutment) shall be proposed.

5.4.3 The engineering geological investigation of concrete/stone masonry dam site shall include:

a) topography and geomorphology of the dam site, thickness and permeability feature of overburden, and extent and depth of riverbed channel;

b) lithologic characteristics and physical-mechanical properties of dam foundation (abutment); distribution and properties of weak intercalations;

c) weathering and unloading characteristics of rock mass at dam foundation (abutment); positions of fault fracture zone, fissure-concentrated zone, fault along the river and low-dip structure plane, and properties and extension status of filling materials, and the quality of rock mass on the dam foundation shall be categorized, depth of stripping limit to ascertain firm foundation shall be worked out, stability of the abutment slopes shall be carried out, the position of usable rock surface shall be identified and the physical-mechanical parameters of the rock (soil) mass shall be determined;

d) distribution, scale, filling conditions and connectivity of Karst cave and passages in the dam foundation (abutment) of soluble rock dam site; distribution and flow of Karstic springs, and the characteristics of replenishment, runoff and discharge;

e) hydrogeological conditions of dam site, permeability and zoning of rock mass of the dam foundation (abutment) and the buried depth of any relative impervious layer, and the anti-seepage scope and depth for the dam foundation (abutment) shall be proposed;

f) assessment of the anti-slide stability, deformation and seepage stability of the dam foundation (abutment), and the suggestions on treatment measures for unfavourable engineering geological issues shall be proposed;

g) investigation of the site of a concrete dam (sluice) built on overburden may refer to the relevant requirements for the site of an earth-rock dam.

5.4.4 The engineering geological investigation of water release structures shall include:

a) topography and geomorphology, stratigraphic lithology, geological structure, weathering and unloading characteristics of rock mass, groundwater table, and physical-mechanical properties of the rock (or soil) mass;

b) stability of slopes on both banks and anti-scour characteristics of rock mass in scouring area;

c) suggestions on physical-mechanical parameters of rock (or soil) mass and mitigation measures.

5.4.5 The engineering geological investigation of underground structures, including tunnels, underground powerhouse, surge tank (chamber) and embedded pipes, etc., shall include the following.

a) Topography and geomorphology, stratigraphic lithology, geological structure, groundwater table, thickness of overlaying rock mass, thickness of weathering and unloading zones of rock mass at, portals, properties and extension length of structural plane of major faults and weak layers and their combination relationship with axes of tunnels or chambers, and the surrounding rocks shall be categorized by their engineering geological properties and the physical-mechanical parameters of rock (or soil) mass shall be proposed.

b) The tunnelling condition and the stability of portals slopes shall be evaluated; the risk assessment of poisonous and explosive gases in tunnel sections that pass through coal measures, oil shale and bituminous strata shall be investigated, and radioactive elements shall be tested and studied in large scale intrusive rock mass, and the stability of surrounding rock in-situ stresses possibility for rock burst in deep tunnel in cave shall be evaluated. The impact of karst caves and underground river systems in soluble rock area on the tunnelling condition shall be analysed.

c) The stability of rock mass at cave roof, high sidewall and conjunction sections with consideration of crustal stress for underground powerhouse and surge tank shall be evaluated according to the ground stress, and treatment measures and suggestions shall be put forward.

d) The relationship between the dip angle of rock strata and the inclination of buried pipes shall be found out when the buried pipes are embedded in the stratified strata, the stability of surrounding rocks shall be evaluated.

5.4.6 The engineering geological investigation of channels shall include:

a) topography and geomorphology, stratigraphic lithology, geological structure, and distribution of landslide and debris flow;

b) segmentation of channels into engineering geological sections according to slope height, properties of rock (or soil) mass and strata attitude, etc., and assessment of the channel seepage and stability of the channel foundation and assessment of potential slope instability problems during construction and operational stages;

c) proposal of the corresponding physical-mechanical parameters of rock (or soil) mass and value of stable slope, and advices on treatment measures shall be suggested.

5.4.7 The engineering geological investigation of penstocks and forebay/surge tank shall include:

a) topography and geomorphology, thickness of overburden, slope of bedrock surface, geological structure, stable conditions of the mountain, physical-mechanical properties of rock (or soil) mass at the forebay/surge tank and the penstock anchorage block foundation;

b) assessment of the stability of slopes along the penstock and the forebay/surge tank, for the anticipated adverse conditions; seismic loading with water forces in slope mass, bearing capacity of foundation and differential deformation, under static and dynamic loading, etc., and proposal of physical-mechanical parameters of rock (or soil) mass.

5.4.8 The engineering geological investigation of the sites of powerhouses shall include:

a) topography and geomorphology, characteristics of rock (or soil) mass, bearing capacity, and deformation properties under static and dynamic loads, permeability and slope stability under adverse conditions;

b) identification of the distribution and properties of weathering zone, overburden, unloading zone and weak intercalation of rock mass for structures on rock foundation, and proposal of the physical-mechanical parameters of rock mass;

c) identification of the thickness, properties, stratified characteristics and permeability of overburden, the depth of groundwater, and the distribution, properties and seismic liquefaction condition of any clay and fine sand layer for structures on soft foundation, and assessment of deformation and permeability stability; and proposal of various physical-mechanical parameters and suggestions on treatment measures.

5.5 Natural construction material

5.5.1 The investigation of natural construction materials shall be carried out according to the requirements at different design stages and the types and quantities of construction materials proposed to be used. The investigation shall be performed from the near to the distant, and the qualitative and quantitative analyses of the natural construction materials shall be carried out and the safety and environmental impacts of proposed material field shall be considered. The construction material for earth-rock dam shall be characterized for its physical, chemical and mechanical properties to be suitable for the specific zones within the dam, the rock for concrete aggregate shall be durable and suitable in accordance with desired standards.

5.5.2 When natural aggregate is insufficient or its excavation is not cost-effective, alternative/processed aggregate sources shall be investigated. In the selection of material sources, the comprehensive utilization of the engineering excavation materials shall be fully considered. In case of outsourcing, the quality of procured natural construction materials shall be reviewed and their capacity to supply shall be evaluated.

5.5.3 The mining conditions and the environmental geological impact shall be investigated, mainly including the distance between 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, and suggestions on treatment and repairs shall be presented as necessary.

6 Hydraulic engineering and energy calculation

6.1 General provisions

6.1.1 Hydraulic engineering and energy calculation shall adhere to the principles of comprehensive utilization of water resources, properly handle the relationship between needs and potentialities, short-term and long-term perspectives, the mainstream and the branches, upstream and downstream interests, as well as the relationship between water resource development and the ecological environment, and land acquisition and resettlement. Water resources shall be developed economically and rationally.

6.1.2 Hydraulic engineering and energy shall be calculated on the basis of the integrated planning of river basin and city or river (reach) planning and power planning. According to the comprehensive utilization requirements, the development task and the power supply scope of the hydropower plant shall be determined, the design dependability and design target year shall be selected, the scale and characteristic values of the hydropower plant shall be determined, the operational modes of the reservoir and hydropower plant shall be researched and the engineering benefits shall be stated.

6.2 Computation of runoff regulation

6.2.1 The computation of runoff regulation shall be based on the regulation performance of the power plant, take into account all kinds of water demand and water supply requirements in an extraordinary dry year, and calculate the energy indicators. For water demand, the ecological flow is calculated according to relevant national or regional regulations and combined with flow observation data. The calculation methods of ecological flow mainly include the hydrological method, the hydraulics method, the combination method, the building block method and the ecological hydraulic method.

6.2.2 The design dependability of a hydropower plant shall meet the following requirements.

a) The design dependability of a hydropower plant may be selected according to the hydropower capacity proportion in the power system described in Table 1.

Table 1 — Design dependability of the hydropower plant

Hydropower capacity proportion in the power system (%)	Below 25	25~50	Above 50
Design dependability of a hydropower plant (%)	80~85	85~90	90~95

b) The design dependability of a reservoir-based hydropower plant with irrigation as the main or other water supply tasks shall be selected according to the requirements of main water use.

6.2.3 The chronological series method shall be applied in the computation of runoff regulation.

a) For non-regulated or daily regulated hydropower plants, the runoff regulation should be calculated by adopting a long series of daily average flow or the average daily flow rate of a typical year.

b) For the annual regulated reservoir, long series shall be adopted for the calculation in accordance with the average monthly (10 day) flow.

6.3 Hydraulic energy calculation

6.3.1 The firm output shall be obtained by frequency analysis method according to the output in the long-series calculation period. For an annual (quarter) regulated hydropower plant, the water supply period is several months (10 days).

6.3.2 The calculation of the characteristic head shall meet the following requirements.

a) Maximum working head is the difference between the normal pool level and the downstream tailwater level corresponding to the firm output for power generation.

b) Minimum working head is the difference between the dead water level and the downstream tailwater level corresponding to the maximum discharge capacity of the hydropower plant or maximum tailwater level.

c) Average head is the arithmetic average value of the average heads in each calculation period of a long series of calculation results.

d) Weighted average head is the ratio of the sum of the products of the average head multiplied with the average output in each calculation period of a long series of calculation results to the sum of the average outputs in each calculation period.

6.3.3 The hydraulic energy indicator of the daily regulated hydropower plant may be calculated by the daily or the hourly time interval. The hydraulic energy indicator of the non-regulated hydropower plant shall be calculated by the daily time interval. Both daily and hourly time interval methods shall meet the following requirements.

a) The daily time interval method.

   1) According to the daily mean flow series at the water intake over the years, the daily flow-duration curve or the daily flow-dependability curve shall be drawn.

   2) According to the head corresponding to various flows and the selected output coefficient, the output duration curve or the output-dependability curve shall be calculated and drawn.

   3) According to the output-dependability curve of the hydropower plant, the relationship curve between installed capacity and power generation shall be calculated and drawn, and then in combination with the selection of the installed capacity of the hydropower plant, the mean annual power generation shall be determined.

b) The hourly interval method.

   1) According to the peak-load operating time in the local daily load diagram, the daily runoff regulation shall be calculated within 24 hours.

   2) When the daily mean flow is greater than the rated flow of the unit, the reservoir regulation may not be considered.

3) When the hydropower plant does not generate electricity and the reservoir cannot reach full storage during the valley-load period, the hydropower plant will not generate electricity during the entire period of valley load and at the beginning of the peak load.

4) When the hydropower plant does not generate electricity but the reservoir can reach full storage and there is surplus water during the valley-load period, the hydropower plant may not generate electricity at the beginning of the valley-load period; the reservoir may firstly reach full storage, and then the hydropower plant can generate electricity at full water level in accordance with the reservoir inflow in the later stage of the valley-load period.

6.3.4 The hydraulic energy indicator of the annual regulated hydropower plant may be calculated by the equal output regulation and the equal flow discharge regulation.

6.3.5 The mean value of the long series of runoff data shall be obtained to calculate the mean annual power generation.

6.4 Load forecast and electric power and energy balance

6.4.1 Following calculations and works shall be based on load forecast:

a) power supply scheme selection, power supply mode determination, electric power and energy balance and flow distribution calculation;

b) power system development, speed determination and phased development plan, preparation of the hydropower plant.

6.4.2 Load forecast shall be mainly based on the existing forecast results which shall be adopted after analysis.

a) With regard to the critical power plant dominating a larger proportion of the system, the load forecast results provided by the relevant institution may be cross checked with multiple methods.

b) The selection of the installed capacity of hydropower plants being a smaller proportion of the system may be determined by economic evaluation and scheme consideration according to the actual situation of the local power demand, while the computation of electric power and energy balance is not required.

c) The installed capacity of the critical hydropower plant, which accounts for a large proportion of the system and is incorporated into the isolated power grid, shall be selected on the basis of the balance of the entire power grid.

6.5 Selection of flood regulation and characteristic flood-control level

6.5.1 In the calculation of flood regulation, technical and economic consideration shall be made for the scale of dedicated discharge structures and limit water level during flood season according to the flood control standard of the project and downstream flood control requirements, so as to determine the flood season limit level, the flood level.

6.5.2 The characteristic water level for flood control shall be determined through technical and economic consideration in combination with the layout and scale of flood discharge structure.

6.6 Selection of normal water level and dead storage water level

6.6.1 The selection of normal water level of the reservoir shall be determined using multi-criteria analysis including technical and economic analysis, according to the cascade development plan, comprehensive utilization requirement, engineering construction conditions, sediment deposition, reservoir inundation and ecological environment. The reservoir inundation and ecological environment shall be regarded as important factors in the comparison of schemes.

6.6.2 The selection of dead storage water level of the reservoir shall be determined by comprehensive analysis according to the comparison of electric power and energy benefit (firm output and power generation) in different schemes, consideration of turbine operating limits, consideration of scouring and silting of sediment, restrictions of the turbine working conditions on the elevation at the inlet, as well as the requirements of other water users on the water level and flow.

6.7 Selection of installed capacity and type of unit

6.7.1 The power supply scope of the hydropower plant should be determined by analysing the development planning of local power system, the scale of the hydropower plant and its function in the power system.

6.7.2 The installed capacity shall be determined after comprehensive comparison in combination with electric power and energy balance by calculating the annual power output, generation benefit and corresponding cost of each installation option on the basis of the analysis of the regulation performance of the reservoir, the comprehensive utilization requirement, the load and characteristics of the system in the design target year, the power supply scope and the power supply structure.

6.7.3 The rated water head of the turbine shall be determined according to the variation characteristics of the head and the weighted average head, and the following requirements shall be met:

a) the rated water head may be selected between the ranges from 0,85 to 0,95 of the ratio of rated head to weighted average head;

b) the rated head should not be higher than the weighted average head during flood season.

6.7.4 The types of the turbine and the number of units shall be selected after comprehensive analysis and comparison according to such factors as power plant output, head variation characteristics, layout of the hydropower plant, local geographical altitude, minimum flow of turbine operation, non-cavitation conditions, equipment manufacturing capabilities and power system operation requirements, as applicable.

6.8 Selection of dimensions of headrace and volume of daily regulation pool

6.8.1 The selection of the headrace dimension and the daily regulating pond volume for the diversion hydropower plant shall be determined through analysis and comparison according to the topographic and geological conditions, ice, sediment deposition, installed capacity of the hydropower plant and the daily operation mode, while appropriate space shall be reserved.

6.8.2 The headrace (channel/tunnel) dimension shall be selected by optimization through scheme comparison by calculating the head loss, the electricity benefits and the cost of various options.

6.9 Analysis of the reservoir sediment deposition and calculation of the backwater

6.9.1 For hydropower plant having the water with sediment, the impacts of sediment size on the erosion of turbine blades and other components passing through the water flow shall be analysed, and the allowable sediment concentration through the turbine shall be proposed.

6.9.2 In the calculation of sediment scouring and silting of the reservoir, various calculation methods may be selected according to the sediment characteristics, sediment management option and availability of the hydrologic data.

6.9.3 In the calculation of reservoir backwater, the natural water surface profile before building the reservoir and the water surface profile of backwater in reservoir within the predicted duration of sedimentation after building the reservoir shall be derived from the design discharge according to the river course conditions, characteristics and operation mode of reservoir.

6.10 Reservoir operation mode and operational characteristics

6.10.1 The reservoir operation mode shall be proposed according to the defined parameters and with consideration of multi-purpose requirements and the situation of existing cascade reservoirs.

6.10.2 The operation characteristics over the years shall be proposed according to the reservoir operating modes.

7 Engineering layout and hydraulic structure

7.1 General provisions

7.1.1 The flood control standard for a hydropower project shall be determined by comprehensive analysis and demonstration in accordance with the requirements of economic, social, political and environmental factors on the flood control safety, by coordinating the relationships between the part and the whole, between the short term and long term, between the upstream and downstream, between the left and right bank, and between the mainstream and its tributaries.

7.1.2 The flood control standard shall be expressed with the recurrence interval (year) of flood prevention. Local/national regulations and can apply regarding protection objectives.

7.1.3 The flood control standards of temporary water retaining and releasing structures used during the construction period of a hydropower plant shall be determined according to the type of structure:

a) when the earth-rock structure is used, the design may be performed on the basis of 5 to 10 years return flood;

b) when the concrete or stone masonry structure is used, the design may be performed on the basis of 3 to 5 years return flood.

7.1.4 The elevation of the dam crest (or the top of the wave wall) of the water retaining structure in the hydropower plant shall be determined according to the static water level under flood conditions, plus corresponding wave run-up, wind banked-up height and freeboard. The elevation of the dam crest of the retaining structure shall not be lower than the normal reservoir water level and the maximum flood level.

7.1.5 The freeboard of hydraulic structures may be determined in accordance with the type of structure and the flood control standard.

7.1.6 Seismic measures shall be adopted for structures in project areas where the ground motion peak acceleration is greater than or equal to 0,1*g* (g = 9,81 m/s^2).

7.1.7 The following data should be collected for design of hydraulic structures.

a) Topographic data: including the regional topographic map in the scale of 1: 10 000 to 1: 50 000, the topographic map of project components in the scale of 1: 200 to 1: 1 000 and project layout in the scale of 1: 2 000 to 1: 5 000.

b) Geological data: the geological survey of project area, including the overburden distribution, lithology, structure, groundwater level and over burden depth of relative confining bed; characteristics of rock stratum, geological structure, hydrogeology, slope stability, karst, landslide and harmful gases along the water diversion system; the crustal stress and the rock burst situation in the region with high crustal stress.

c) Hydrological and meteorological data: all hydrological characteristics of the river in the project area such as runoff, flood, corresponding water level and sediment load; meteorological factors of the project area, including sunlight, rainfall, snowfall, wind, air temperature, humidity and water temperature.

d) Results of hydraulic energy calculation: including the characteristic water level of the reservoir (normal reservoir level, flood level, minimum draw down level for power generation), the characteristic parameters of the flood discharging structures (orifice size, control elevation, dispatching mode), etc.

e) Construction material data: including the distribution of construction material in and around the project area, including the quality, quantity, physical and mechanical properties of natural construction material (rock blocks, sandy gravel, clay, etc.), as well as the characteristic parameters, transportation distance and cost of material such as cement and structural steel, etc.

f) Sediment data: the content, particles, hardness, unit weight and movement of bed load and suspended load in heavily sediment laden river. The deposition morphology and elevation of the sediment in the reservoir area also shall be collected for the water intake.

g) Pollution data: for the river channel with heavy trash, the source, variety, quantity and drifting pattern of the trash shall be collected.

h) Ice data: for the river in a frost region, the icing period, floating ice features and floating ice quantity; the size of the ice blocks/flakes and the thickness of the ice layer; the operating data for the hydropower plant intake in winter under similar conditions shall be collected.

7.2 General engineering layout

7.2.1 Hydropower plants may be classified as dam-toe, riverbed, diversion and hybrid hydropower plants according to the developing mode:

a) dam-toe mode, in which the powerhouse is located at the dam toe;

b) riverbed mode, in which the powerhouse locates at the riverbed, functioning as a part of water retaining structures;

c) diversion mode, in which the water head are created by diversion structures such as canals and/or tunnels;

d) hybrid mode, in which the water heads are created by a dam plus a canal and/or tunnel.

7.2.2 The layout of hydropower project may be performed under the following principles.

a) The requirements of flood control, power generation, navigation, fishery, forestry, road transportation, and environment shall be comprehensively considered.

b) The structures of project shall be compactly laid out to meet the functional requirements, strength and stability, so as to ensure them to work normally under any working conditions. The total construction cost and annual operating cost of the project shall be reduced for convenient operation and management.

c) The structure may be used for multiple purposes, or a temporary structure and permanent structure may be combined in the layout.

d) The construction diversion method, the construction method of main structures and the construction schedule shall be considered for the convenient construction and short construction period.

e) The aesthetic of the project layout shall be integrated with the surrounding environment.

7.2.3 The dam site selection shall meet the following requirements:

a) convenient for construction diversion;

b) the terrain near the dam site relatively wide and open;

c) the project layout easy to manage;

d) consideration of external traffic conditions.

7.2.4 The dam site comparison and selection shall meet the following requirements.

a) It is preferable to select the dam site with less submergence, less land acquisition and less rehabilitation/resettlement.

b) The impact on the environment shall be considered for dam site selection, and sensitive objects should be minimum.

c) The representative dam axis, dam type and project layout of each dam site shall be determined by comparison, and the dam site shall be selected and determined by comprehensive technical and economic consideration.

7.2.5 The sluice should be located on a straight and relatively stable reach, and the leakage, stability and deformation conditions of the sluice foundation and sluice shoulders on both sides shall be considered.

7.2.6 With regard to the sluice on a heavily sediment laden river, sediment flushing sluice (desilting sluice) or flood-discharging and sediment flushing sluice shall be set at the adjacent position of the intake sluice or the water intake of other intake structures, and the sediment deposition problem at the intake sluice or other intake structures shall be properly resolved.

7.2.7 The layout of the water diversion tunnel shall take into account factors such as topography, geology, hydraulics, construction, operation, structures along the route, the general layout of the project and the influence on the surrounding environment.

7.2.8 The intake of the riverbed powerhouse shall avoid the deposition and erosion of sediment, the blockage from floating trash and ice. When the powerhouse is adjacent to the spillway, a long enough divide wall shall be constructed between them; the powerhouse, switchyard and substation shall be kept at a certain distance safe from the jet of flood discharge.

7.2.9 To design fish pass, the characteristics of the river and the habits of fish to be fully studied and understood, and determine the reasonable arrangement of fish pass by studying the hydraulic parameters such as velocity distribution and flow in the fish pass under different water flow conditions in the stream, so as to fully functioning of fish pass, protect fish resources and maintain the biodiversity of the river.

7.2.10 The layout of the powerhouse shall meet the following requirements.

a) The inlet and outlet channels shall be as short as possible; the water flow shall be smooth; the head loss shall be small and the water outlet shall not be deposited or impacted by the ice.

b) The tailrace shall be sufficiently deep and wide; the plane curvature shall not be extensive, and the depth shall vary gradually and the tailrace shall be smoothly connected to the natural river flow or channel.

c) The water flow or energy dissipation facilities at the outlets of the discharging structures shall be laid to avoid raising the tail water level of the hydropower plant as much as possible.

7.3 Water retaining structure

7.3.1 The type of water retaining structures shall be determined by technical and economic consideration on the basis of the hydrological condition, the topographical and geological conditions, dam height, construction materials, operating conditions, construction methods, construction duration, construction quantities and investment.

7.3.2 The crest of water retaining structures shall be kept higher than the maximum flood level, the wave wall shall be arranged on the upstream side of the dam crest. The crest elevation of the wave wall shall be kept higher than the crest elevation of the wave. The crest elevation of the wave wall within the normal reservoir level and the maximum flood level shall be calculated respectively, and the higher one shall be selected as the design crest elevation of the wave wall.

7.3.3 The crest width of non-overflow dams shall be determined in accordance with the profile design and operation management requirement, and shall not be less than 3 m. The reinforced concrete wave walls connected with the dam body shall be of a height of 1,2 m on the upstream side of the dam crest. Handrails shall be set on the downstream side of the dam crest. When the mobile hoist is used on the dam crest, the dam crest width shall meet the requirement of installing the portal crane tracks.

7.3.4 The weir surface curve of the overflow dam section shall meet the following requirements.

a) The power curve may be used if an open overflow is arranged.

b) The parabola of orifice overflow may be adopted if the breast wall is arranged and used for water retaining.

c) Other weir surface curves may also be applied based on study and testing.

7.3.5 The joints of the concrete dam body shall be determined by comprehensive comparison in accordance with the geological and topographical conditions, the dam body layout, section size of the dam body, and the temperature stress and construction conditions. The interval between transverse joints should be 15 m to 20 m and the interval between longitudinal joints should be 15 m to 30 m.

7.3.6 The slope of the concrete faced rockfill dam shall meet the following requirements.

a) When the construction of dam is from hard rockfill material of good quality, the gradient of the upstream and downstream dam slopes may be 1: 1,3 to 1: 1,4.

b) When the dam construction materials are natural sandy gravel aggregates, the gradient of the upstream and downstream dam slopes may be 1: 1,5 to 1: 1,6.

c) When the dam construction materials are soft rock materials and the dam is built on the soft foundation, the gradient of the dam slope shall be determined by stability calculation.

7.3.7 The concrete faced rockfill dam body shall be zoned according to the aggregate sources as well as the requirements of the strength, permeability, compressibility, construction convenience, and economic rationality. The dam body may be zoned, from upstream to downstream, into the cushion layer area, transitional area, main rockfill area and downstream rockfill area. The special cushion layer area shall be arranged below the peripheral joints. The water permeability of the dam materials in different areas should be increased from upstream to downstream according to the hydraulic transition requirement.

7.3.8 The thickness of the face slab of the rockfill dam shall be such that the hydraulic gradient for the face slab shall not be greater than 200. The vertical joints of the face slab may be 12 m to 18 m.

7.3.9 The toe slab of rockfill dam should be placed on the fresh bedrock which is hard, erosion resistant, groutable, and moderate to weak weathering rocks. The width of the toe slab may be determined in accordance with the permissible hydraulic gradient of the bedrock beneath the toe slab and the foundation treatment measures; its minimum width should be 3 m. The thickness of the toe slab may be less than the thickness of the connected face slab but shall not be less than 0,3 m.

7.3.10 The concrete of face slab and toe slab of rockfill dam shall have relatively high durability, anti-seepage, crack resistance and construction workability. Concrete strength grade shall not be lower than C25, the anti-seepage grade shall not be lower than W8 and the frost resistance grade shall meet the requirement of freeze thawing.

7.3.11 The rolled earth-rock dam may adopt the types of the earth and rockfill dam with earth-based anti-seepage body, earth and rockfill dam with artificial anti-seepage body and overflow earth and rockfill dam. The soil and rock materials for filling the dam body shall have the physical and mechanical properties adaptive to their intended use and have relatively good long-term stability.

7.3.12 The static stability of the earth and rockfill dam shall be calculated with the Swedish circle method for the homogeneous dam, the core wall dam and the thick inclined earth dam; the sliding wedge method may be used for the thin inclined earth dam, the thin core wall dam and the dam body with soft soil interlining in the dam foundation. In the steady seepage period, the effective stress shall be used for calculation.

7.3.13 For the earth and rockfill dam, the total settlement of the dam body and dam foundation as well as the settlement during the construction period shall be calculated.

7.3.14 The dam foundation shall have sufficient integrity and durability. The dam foundation treatment design shall meet the requirements of anti-slip stability, reduce uneven settlement and prevent the deterioration of the rock property under the long-term action of water.

7.3.15 Dam foundation excavation shall meet the following requirements.

a) The foundation surface of a gravity dam should be excavated into big steps with obtuse angle; the height difference of the steps shall be in harmony with the dimension of the concrete placement blocks and the position of the joints, and the thickness of the dam body concrete at the dam toe; the height difference should not exceed 5 m.

b) The arch dam foundation should be excavated into radial surface.

c) The excavation face of the toe slab foundation of a concrete faced rockfill dam shall be smooth and shall be kept away from steep ridges and adverse slopes.

7.3.16 The design of slope treatment and reinforcement shall take the factors such as topographical and geological conditions, construction technology level and degree of difficulty into consideration, and the selection shall be made after technical and economic consideration.

7.3.17 A complete surface interception and drainage system should be set up in the slope treatment and reinforcement. If the slope stability is closely related to the rock or soil mass saturation and the ground water rise caused by the surface water infiltration, anti-seepage measures should be provided both within the slope and near the slope area.

7.3.18 Slope treatment and reinforcement shall take environmental protection into account and be in harmony with surrounding buildings and the environment.

7.3.19 With regard to a medium dam with a dam height of more than 30 m, the temperature control design shall be performed, and temperature control standards and crack-prevention measures shall be proposed.

7.4 Water release structure

7.4.1 The type, dimension and elevation of the water release structure shall be determined after technical and economic consideration according to topographical and geological conditions, layout of the project, sedimentation, release volume, construction quantity, construction and investment, etc.

7.4.2 For concrete and stone masonry dams, overflow crest should be adopted, and dam release orifice or discharge tunnel may be adopted as well.

7.4.3 For earth-rock fill dams, open spillways should be used as the water release structure; if limited by conditions, free-flow tunnels with open intake may be adopted. The design of the connection between the spillway and the earth-rock dam shall meet the requirements of strength, anti-sliding stability and seepage stability.

7.4.4 The discharge and energy dissipation shall be reasonably selected for the layout of spillway; the outlet water flow shall be smoothly connected to the downstream river channel to avoid serious erosion and scouring of the downstream river bed and bank slopes by water flow, and the sedimentation of the river channel, so as to ensure the normal operation of other structures of the project.

7.4.5 The weir crest of side spillway may be provided without a gate. The cross-section of the side channel should be a narrow-deep trapezoidal cross-section; the slope on the side of the hill may be determined according to the characteristics of the bedrock and the slope on the side of the weir may be 1: 0,5 to 1: 0,9.

7.4.6 The top elevation of the gate pier, the breast wall or the quay wall of the spillway shall not be lower than the maximum flood level plus the freeboard when the maximum flood is discharged; and the crest elevation shall not be lower than the maximum flood level or the normal reservoir level plus the calculated height of the wave and the freeboard when the water is blocked. When the spillway is close to the dam abutment, the top elevation of the control section shall be consistent with the dam crest elevation.

7.4.7 The height of the side wall of the discharge chute section shall be based on the water surface line after taking into account the fluctuation and aeration plus a freeboard of 0,5 m to 1,5 m. For the parts with complex hydraulic conditions such as the contraction (diffusion) section, and the bend section, a large value should be adopted. When the discharge chute contains the bend in the plan, the transverse water level difference of the bend section shall be calculated.

7.4.8 The elevation of the deflecting bucket shall ensure that free deflecting flow can be formed, which may be slightly lower than the maximum downstream water level.

7.4.9 A series of calculations shall be carried out for different flow rates in the hydraulic design of trajectory bucket energy dissipation. The safety jet trajectory length, the width of the water jet into water and the maximum allowable scour depth shall be determined under the premises of not influencing the stability of the bucket lip foundation and the bank slopes on both sides, and of ensuring the safety of the adjacent structures.

7.4.10 The sluice chamber may employ the open-type, breast wall, culvert-type or double-deck structure according to the discharging features and operational requirements.

a) With regard to the sluice with relatively high elevation of sluice sill and low water retaining height, the open-type structure may be adopted. The structure of the open-type sluice chamber may be integral or separated according to the foundation conditions and stress situations.

b) With regard to the sluice with relatively low elevation of sluice sill and high-water retaining height, the breast wall or culvert-type structure may be adopted. The settlement joint shall not be provided within the culvert-type sluice chamber.

7.4.11 The top elevation of the sluice shall be determined according to the two operational modes of water retaining and water discharging.

a) In case of water retaining, the sluice top elevation shall not be lower than the sum of the normal reservoir level (or the maximum water retaining level) of the sluice plus the calculated height of the wave and the corresponding safety freeboard.

b) In case of water discharging, the sluice top elevation shall not be lower than the sum of the flood level and the corresponding freeboard.

7.4.12 The elevation of sluice sill shall be determined by technical and economic consideration in accordance with the river (channel) bottom elevation, water flow, sediment, topography and geology as well as the construction and operational conditions combined with the selected weir type, sluice type and total net width of the sluice orifices.

7.4.13 The sluice orifice shall meet the following requirements.

a) The total net width of the sluice orifices shall be determined by technical and economic consideration according to the discharge characteristics, geological conditions of the downstream river bed and the requirements of safe discharge, combined with the selection of the diameter and the number of sluice orifices.

b) The diameter of the sluice orifice shall be determined by comprehensive analysis in accordance with the gate foundation conditions, operational requirements and gate structure type, hoist capacity as well as the fabrication, transportation and installation of the gate. When there are less than eight sluice orifices, the number of orifices should be odd number for operation safety.

7.4.14 The section length of the sluice on the rock foundation should not exceed 20 m, and the section length of the sluice on the soil foundation should not exceed 35 m. The permanent joints may be vertical cut-through joints, inclined-lapped joints or serrated-lapped joints; the joint width may be 20 mm to 30 mm.

7.4.15 The gate pier shall meet the following requirements.

a) The contour design of the gate pier shall meet the requirements of smooth flow through the sluice, small lateral contraction and large flow capacity. The upstream pier head may be made semi-circular and the downstream pier head in streamline form.

b) The thickness of the gate pier shall be determined according to the diameter of the sluice orifice, stress conditions, structural requirements and construction methods. The minimum thickness should not be less than 0,4 m at the gate slot of the gate pier of the plane gate.

7.4.16 The gate slot of the service gate shall be arranged in the position of the gate pier with relatively smooth flow, and its breadth-depth ratio should be 1,6 to 1,8. The net distance between the bulkhead gate slot and the service gate slot should not be less than 1,5 m.

7.4.17 The beam bottom elevations of the service bridge, maintenance bridge and access bridge shall be at least 0,5 m higher than the maximum flood level; if there is floating ice, the elevation shall be 0,2 m higher than the floating ice surface.

7.4.18 The anti-seepage and drainage layout of the sluice shall be determined by comprehensive analysis according to the geological conditions of the sluice foundation and the difference between upstream and downstream water levels, combined with the layout of the sluice chamber, energy dissipation and anti-scour and the connections to both banks. The length of the blanket may be determined according to the anti-seepage requirements of the sluice foundation and should usually be 3 to 5 times of the maximum difference between upstream and downstream water levels.

7.4.19 The underflow energy dissipation should be used on the downstream side of the sluice.

7.4.20 The apron shall be flexible, water-permeable and rough in surface; its composition and anti-scouring capacity shall be adaptive to the water flow velocity. The gradient of the apron should be equal to or less than 1: 10; the anti-scour trench (or anti-scour wall) shall be arranged at its end; the cushion layer shall be arranged beneath the apron.

7.4.21 The connection of both banks of the sluice shall meet the following requirements:

a) ensure the stability of the bank slopes;

b) improve the water intake/outlet conditions of the sluice;

c) enhance the discharge capacity and energy dissipation and anti-scour effects;

d) satisfy the lateral anti-seepage requirement;

e) loosen the side load's influence on the floor of the sluice chamber;

f) be favourable for environment;

g) be adaptive to the layout of the sluice chamber;

h) the average divergence angle of the downstream wing wall should be 7° to 12° on each side.

7.4.22 The structural design of the sluice shall be performed according to the structure stress conditions and the engineering geological conditions. The stability calculation of the sluice chamber on the soil foundation shall meet the following requirements.

a) Under various calculation conditions, the average foundation stress of the sluice chamber shall not be more than the allowable bearing capacity of the foundation, and the maximum foundation stress shall not be more than 1,2 times the allowable bearing capacity of the foundation.

b) The ratio of the maximum and the minimum foundation stresses of the sluice chamber shall meet the provision for allowable value in Table 2.

c) The anti-sliding stability safety factor along the foundation surface of the sluice chamber shall not be less than the safety allowable value (1,20 for basic load combination and 1,00 to 1,05 for the special load combination).

Table 2 — Allowable value for ratio of the maximum and the minimum foundation stresses of the sluice chamber on the soil foundation

Foundation soil	Load combination	
	Basic combination	Special combination
Soft	1,50	2,00
Medium hard	2,00	2,50
Hard	2,50	3,00

7.4.23 If the sluice chamber is equipped with two bulkhead gates or with only one bulkhead gate, the anti-floating stability shall be calculated when the service gate and the bulkhead gate are used for inspection. The anti-floating stability safety factor of the sluice chamber shall not be less than 1,10 under basic load combination and shall not be less than 1,05 under special load combination.

7.5 Water diversion structure

7.5.1 The types of the water diversion structure shall be determined after technical and economic consideration according to the development mode, operational requirements, topographical and geological conditions and types of water retaining structures, combined with the general layout and construction conditions of the project.

7.5.2 The layout principles of the water intake and the design requirements for sediment control and anti-ice shall meet the following provisions.

a) At various operating water levels, the water flow is smooth with steady flow pattern and uniform inflow and meets the requirements for diversion flow.

b) Air-entraining funnel vortices shall be avoided.

c) The equipment for the water intake shall be complete, the gates and hoists shall be accessible, easy to maintain and reliable to operate, and the water filling, ventilation and traffic facilities shall be unobstructed.

d) The effective sediment control measures shall be taken for the water intake on the heavily sediment laden river. The sediment control for the water intake shall be designed to include sediment guiding, retaining, discharging, settling and flushing measures.

e) Effective trash guiding, discharge and cleaning measures shall be taken for the water intake on the river with heavy trash. The requirements of decontamination and water diversion shall be taken into account in the trash rack facilities. The opening area of the trash rack shall be guided by the flow velocity through the rack. The flow velocity should be 0,8 m/s to 1,2 m/s.

f) Necessary anti-ice measures shall be taken for the water intake in severe cold regions. The water intake shall avoid the direct impact of floating ice, optimize the reservoir regulation and limit the production of floating ice. The anti-ice design for the water intake shall adopt measures such as ice guiding and discharging.

7.5.3 The open water intake on the bank should be selected on the steady river reach and should be laid out near the main channel, but it shall not be laid out on the river reach with a wide river bed and scattered mainstream. The water intake shall not be arranged near the junctions of tributaries or ravines carrying a large amount of bed load.

7.5.4 Deep-hole intake should be adopted for pressure diversion system on the bank; the deep-hole intake may be classified as bank-tower intake, shaft intake and bank slope intake according to their structural features and gate position, and shall be selected combined with the geological and topographical conditions. The tower intake should not be arranged in high seismic region. The deep-hole intake shall ensure sufficient submerged depth below the minimum upstream operating water level.

7.5.5 The water intake shall be of sufficient stability, strength, rigidity and durability.

7.5.6 The desilting tank should be set up adjacent to the inlet of the headrace. When limited by the topographic conditions or the sand flushing head cannot meet the requirements, the desilting tank may be moved down along the diversion channel to an appropriate position. The layout of the desilting tank shall make rational use of topography and geological conditions to avoid bad areas, otherwise corresponding engineering measures shall be taken.

7.5.7 The hydraulic cleaned desilting tank is generally used, with sufficient sand flushing head and flow rate. If the terrain is open, the desilting tank should be cleaned regularly, and if the terrain is narrow, the desilting tank should be continuously cleaned.

7.5.8 The routine selection of the diversion tunnel shall meet the following requirements.

a) The tunnel route should be straight; the turning radius should not be less than 5 times the tunnel diameter (or width); the turning angle should be less than 60°; and straight sections should be placed at both the start and end of any bend section and the length should be greater than 5 times the tunnel diameter (or width).

b) The portals should be located at places with simple geological structures, stable slopes, shallow weathering or overburden. Excavation at steep and high banks shall be avoided.

c) The direction of the hole line, rock stratum, fracture surface and other weak zones should have a large angle of intersection. For an integral block structured or thick stratum rock mass, the intersection angle should not be smaller than 30°; for a thin layered rock mass, the angle should not be less than 45°. Heavily fractured zone, weak structured plane and areas full of groundwater should be avoided, and engineering measures shall be taken if unavoidable.

d) The thickness of rock mass between two neighbouring tunnels should not be less than 2 times the tunnel diameter (or width). The thickness may be reduced if the rock mass is in good condition, but shall not be less than one tunnel diameter (or width).

e) The setup shall be favourable for the layout of construction adits.

f) The surge tank of the pressure diversion tunnel should be close to the powerhouse and should avoid unfavourable geological conditions.

7.5.9 The diversion tunnel for power generation is usually a pressure tunnel. The pressure tunnel should use the section in accordance with geological conditions. The free-flow tunnel should employ the straight wall section with an arch. Considering the construction requirements, the minimum size of the cross section shall meet the following requirements.

a) The inner diameter of the tunnel section should not be less than 1,8 m.

b) The height of the non-circular section should not be less than 1,8 m and the width should not be less than 1,5 m. The tunnel width should be greater than 2,2 m in the case where its length is longer than 1,5 km.

7.5.10 With regard to the relatively long tunnel, multiple section shapes or lining patterns may be used in accordance with geological conditions. The cone angle of the transition section of the pressure tunnel should be 6° to 10°, and its length should not be less than 1,5 to 2 times the tunnel diameter (or tunnel width).

7.5.11 Under the most unfavourable operating conditions, the pressure head above the tunnel roof along the whole pressure diversion tunnel shall not be less than 2,0 m.

7.5.12 According to the strength, integrity and permeability of the surrounding rocks, the diversion tunnel may be applied with shotcrete-anchorage lining, concrete lining, reinforced concrete lining or steel plate lining. The thickness of monolayer reinforced concrete lining should not be less than 0,3 m; the thickness of bilayer reinforced concrete lining should not be less than 0,4 m. The concrete strength shall not be lower than grade C20.

7.5.13 The length of the placed section along the tunnel route shall be determined by analysis in accordance with the placing capacity and the thermal shrinkage. The length should be 6 m to 12 m. The circumferential joints on the bottom arch and the side/crown arch shall not be staggered.

7.5.14 The top of the concrete and reinforced concrete lining shall be backfilled. The scope, hole spacing, row spacing, grouting pressure and grout density of the backfilling shall be determined by analysis according to the type of lining structure, working conditions in the tunnel and the construction method.

The depth of the grouting hole into the surrounding rocks shall be more than 50 mm. For sections with poor geological conditions, consolidation grouting should be applied.

7.5.15 The layout of surge tank shall be designed on the basis of the calculation of unit transient performance and the analysis of operating conditions and shall be finalized after technical and economic consideration of the function of the hydropower plant in the electric power system, the topographical and geological conditions, and the layout of penstocks. The cross-sectional area and height of the surge tank shall meet the requirements for fluctuation stability and surge wave respectively. The surge tank should be located underground or on surface in accordance with local topographic conditions and constructed using anchor and shotcrete lining, plain concrete lining, reinforced concrete lining and steel, etc. in accordance with local material availability.

7.5.16 The selection and layout of the diversion channel route shall meet the following requirements.

a) Areas with complicated geological structural features, high permeability, land collapse and landslides, (wet) subsidence and mud-rock flow should be avoided; deep excavation and high fill quantities shall be avoided, and land acquisition and house demolition shall be kept to a minimum.

b) The channel route should be straight. If a bend is necessary, the bending radius of lined channel should not be less than 2,5 times the channel water surface width, and the bending radius of unlined channel should not be less than 5 times the water surface width. In frigid regions, the route of channel should be set along the sunny slope, and the bending radius should not be less than 5 times the water surface width.

7.5.17 The selection scope of the design flow velocity of the water diversion channel of the hydropower plant shall meet the following requirements:

a) 1 m/s to 2 m/s should be adopted for the lined channel;

b) 0,6 m/s to 1,0 m/s should be adopted for the earth channel.

7.5.18 The layout of the forebay shall meet the following requirements.

a) The forebay should be located away from the areas with landslide, fracture developed along the slope and high slopes. Taking into account the route of penstock and the powerhouse location, the forebay shall be located on the solid and steady foundation with small permeability. The impact of hydrological and geological changes on the stability of slopes after construction of the forebay shall be analysed.

b) The volume and depth of the forebay shall meet the requirements of minor fluctuation of the water level and sedimentation when the load of the hydropower plant changes. The regulating requirements shall be met when the forebay serves as a regulation pond.

c) The connection part of the diversion channel and forebay should be set up symmetrically, while the expansion angle should not be larger than 12°, and the longitudinal gradient at the bottom should be less than or equal to 1: 5.

d) The minimum submerged depth of the top edge of the penstock inlet shall meet the requirement of the minimum submergence depth. The elevation of the base floor at the end of the forebay shall be at least 0,5 m lower than the base slab of the intake chamber.

e) Sediment releasing and emptying facilities shall be installed in the forebay and the type of these facilities should be sand flushing gallery (tunnel). In frigid regions, ice retaining, ice guiding and ice discharging facilities shall also be installed.

f) The layout of the forebay shall be compact and reasonable to ensure smooth water flow, flexible and reliable operation and a safe and economical structure.

g) Safety handrails and walking platforms should be provided for easy operation, inspection and maintenance.

h) Trashrack arrangement should also be provided for the forebay with incoming open channels.

7.5.19 The channel anti-seepage materials usually include soil, cement soil, masonry, membrane, bituminous concrete and concrete. The channel anti-seepage works shall be adapted to local conditions and obtained locally.

7.5.20 The route of the exposed penstock shall be kept away from the location where the landslide or collapse may occur. The emergency drainage and anti-scour facilities shall be set up.

7.5.21 The exposed penstock should be made into sections, and the anchor block should be arranged at the bends (plan as well elevation). The bottom of the exposed penstock shall be at least 0,6 m above the ground surface.

7.5.22 The bend radius of the penstock should not be less than 3 times the pipe diameter. The plane bend and the vertical bend close to each other should be combined into a three-dimensional (compound) bend. The bend and the tapered section close to each other should be combined into a tapered bend pipe.

7.5.23 The thickness of the penstock wall shall meet the requirements of strength and stability against external pressure and shall be defined after stress analysis. The maximum internal water pressure to be endured by the penstock shall be defined after water hammer analysis and calculation.

7.5.24 The inner surface of the penstock shall be sprayed with wear-resistant, anti-rust and anticorrosion coatings; and the external surface shall be treated against corrosion in accordance with the layout method of penstock. Anti-freezing facilities shall be installed in frigid regions. cathodic protection may be provided of the steel penstocks where water quality of having crustation and corrosion properties.

7.5.25 The bifurcated pipe of the penstock may be asymmetrically branch-shaped, symmetrically Y-shape or three-branch-shape. The bifurcation angle may be defined according to the shape and material of the bifurcated pipe, which should be 30° to 60° for reinforced concrete bifurcated pipes and 45° to 90° for steel bifurcated pipes.

7.5.26 For welded steel pipes, welding inspection and water pressure test shall be performed. The test pressure value shall not be less than 1,25 times the maximum internal water pressure under normal working condition, nor shall it be less than the maximum internal water pressure under special working condition.

7.5.27 For Glass Reinforced Plastics (GRP) pipes, standard manufactures specifications be used.

7.6 Powerhouse structure

7.6.1 The type of the powerhouse shall be selected after technical and economic consideration of the project layout, topographical and geological conditions, variation amplitude of upstream and downstream water levels in the tail race channel and flood level in water going stream/river, etc.

7.6.2 The layout of the surface powerhouse shall comply with the following principles.

a) The powerhouse shall be in harmony with other project structures.

b) For the drainage system on the powerhouse site, dedicated drainage pumps shall be installed when gravity drainage is impossible.

c) For the powerhouse built into the side of the mountain, necessary facilities shall be installed on the slopes to prevent mountain torrent and rolling stones.

d) The switchyard and the main transformer yard should be close to the powerhouse. When limited by topographical conditions, the main transformer and the switchyard may be laid out separately.

e) The topographic elevation of the powerhouse should take into account the water level in the tail race channel corresponding to the water level in the river section in accordance with flood conditions.

7.6.3 The fire lane shall be set in the plant area, the width of which should not be less than 4,0 m, and it should be used as the access road as well.

7.6.4 For the internal layout of the powerhouse, the dimensions and space of the various parts shall be reasonably determined and distributed according to the scale of the hydropower plant, powerhouse type, environmental features, civil engineering design, layout of the electromechanical equipment, operation maintenance, installation and overhaul.

7.6.5 The dimension of the powerhouse shall be determined keeping in view the head, flow, dimensions of the turbine and generator, accessibility and safety consideration. The plan dimension of the powerhouse for the horizontal unit shall be determined according to the plane dimension (diameter) of the spiral case and the length of the entire unit bay. The plane dimension of the powerhouse for the vertical unit shall be determined according the dimension (width) of the generator base and the length of the unit. The plane dimension of the powerhouse for the bulb tubular unit shall be determined according to the size of the flow path, the thickness of the gate pier and the layout of the inlet and outlet gates and the hoist. In addition, auxiliary equipment such as the main inlet valve, the governor and the local control panel as well as the pedestrian path in the powerhouse shall be considered. The height of the powerhouse shall be determined by the hoisting conditions of the equipment and the installation elevation of the turbine.

7.6.6 The spacing between units in main powerhouse shall meet the following requirements.

a) For horizontal unit, installation and maintenance requirements shall be met. The generator rotor shall be able to be drawn out and inserted if necessary, and the net spacing between units shall not be less than 1,5 m to 2,0 m.

b) For vertical unit, it should be determined on the plan according to the diameter of the fan cover of the generator, the size of the spiral case and the draft tube. The thickness of the separating piers between the adjacent concrete spiral cases and between the draft tubes should not be less than 1,0 m to 2,0 m (use the high value when the permanent joint is arranged). The thickness of the separating pier between the metal spiral cases should not be less than 1,0 m. The net spacing between the fan cover plates of the generator should not be less than 1,5 m to 2,0 m. The necessary concrete thickness between the draft tubes shall be considered for the spacing between units of the powerhouse within dam and the overflow type powerhouse.

c) For the bulb/tubular units, it shall be determined according to the width of the flow path, the number of units and the joint separating method. The additional length of the side unit bay shall be determined by the boundary line of the bridge crane hook, which should be 3 m to 5 m.

d) Foundations of the generator should take into account the static and dynamic loads, as well as the bearing capacity of the soil to dampen the vibrations

7.6.7 The control dimension of the main machine hall for the main powerhouse shall be determined according to the following principles.

a) The length and width of the main machine hall shall be determined by taking into account the number of units, the flow passage components of the turbine, the dimensions of the generator and the air duct, the lifting mode of the crane, the position of the main inlet valve and governor, the structural requirements of the powerhouse, the operation and maintenance, and mobility in the powerhouse.

b) The flow passage components of the turbine and the supporting modes of the unit shall be selected according to the data provided by the manufacturer and the requirements of the hydraulic structure.

c) When the length of the unit bay is controlled by the dimension of the spiral case, the length of the unit bay shall meet the spatial requirements required by the installation of the metal spiral case, and the minimum spatial dimension should not be less than 0,8 m; for the concrete spiral case, its wall thickness shall be determined by the strength, rigidity and structural requirements.

d) When the length of the unit bay is controlled by the dimensions of the generator and its air flue, the spacing between units shall not only meet the requirements of equipment layout, but also keep the necessary width of the passage.

e) The length of the unit bay in the powerhouse at dam toe should be coordinated with the dam body joints. For the diversion powerhouse through the tunnels, it shall also be adaptive to the thickness of the rock mass between the penstocks.

f) When the sediment discharging and draining holes are arranged in the unit bay, the structural strength, composition and construction requirements of the holes shall be fulfilled at the same time.

g) The length and width of the main machine hall shall meet the requirements of the effective working scope of the crane hook, the layout of the main inlet valve and governor, the mobility in the powerhouse and the structural size.

h) The structural dimensions of the main powerhouse above water and under water should be concurrently coordinated and considered.

i) The length of the side unit bay (unit in the ending bay) shall be determined in combination with the position of the erection bay, the height difference between the main machine hall and the erection bay as well as the lifting scope of the crane.

7.6.8 The dimension and layout of the erection bay in the main powerhouse may be determined in line with the following principles.

a) The area of the erection bay shall be comprehensively determined by the powerhouse type, unit structure, installation progress and expanded overhaul of one unit.

b) When the data in unavailable, the length of the erection bay may be 1,25 to 1,5 times the length of the unit bay; with regard to the hydropower plant with multiple units, the area of the erection bay may be increased as required or an auxiliary erection bay may be arranged.

c) The ground elevation of the erection bay should be the same as that of the generator floor; if the downstream flood level is higher than the ground elevation of the generator floor, the elevation of the erection bay may be increased to higher than flood water level.

d) The layout of the erection bay shall satisfy the requirements of the transportation, installation and overhaul of the equipment or the access of vehicles for handling according to the number of installed units.

e) The erection bay may be laid out at one end, two ends or in the middle section of the main powerhouse.

f) The layout of the erection bay shall be adaptive to the transportation methods for the main equipment.

7.6.9 The layout and top elevation of the crane rail in the main powerhouse shall be determined according to the following requirements.

a) The requirement of lifting the main parts of the unit shall be met. When the inlet valve is located in the powerhouse, the centreline shall be laid out within the working scope of the crane hook.

b) The top elevation of the crane rail shall be determined according to the crane specifications as well as the lifting requirements during installation and overhaul of the units, and it shall meet the requirements for loading/unloading the goods on the transportation vehicle in the powerhouse.

c) The net distance between the crane top and the powerhouse ceiling (or the lower chord of the roof truss and the lamp bottom) shall not be less than 0,3 m.

d) The necessary space for removing and installing the reducer cover, the coiling block and the motor shall be reserved at the appropriate positions of the powerhouse roof.

e) In addition to the space requirement of the travelling cart, the clearance for the installation and overhaul of the travelling mechanism of the cart as well as the turn-out space for personnel shall be reserved at the appropriate positions in the interval between the end edge of the crane and the upstream/downstream walls.

f) The width of the crane beam top face (including the walkway of the crane beam) shall meet the passing requirements of the operating personnel, and the ladders for the operators (in the case where it is driver cab-equipped) and the overhaul personnel to get on or off the crane shall be provided.

g) The safe distance between the lifted component and the installed equipment, structure and ground shall not be less than 0,3 m.

7.6.10 The mobility in the powerhouse shall comply with the following provisions:

a) The mobility in the powerhouse (including the stairway, spiral staircase, ladder stand, lifting holes, horizontal passage and gallery) shall be convenient for management and beneficial for overhaul and quick troubleshooting.

b) The dimension of the main passage as well as the width, the slope and the emergency exit shall meet the requirements of the electromechanical and fire protection design codes.

c) The straight horizontal passage throughout the entire powerhouse should be arranged on the generator floor and the turbine floor.

d) One stairway should be arranged every 1 to 2 unit bays between the main floors, including the generator floor, the busbar floor and the turbine floor; at least two stairways should be arranged in the entire plant.

e) The lifting holes for installation and overhaul should be arranged in the main powerhouse within the working scope of the crane hook and in the auxiliary powerhouse required for lifting of the electromechanical equipment.

7.6.11 The layout and dimensions of the turbine pit shall meet the requirements of unit installation and maintenance; the strength and rigidity of the unit supporting structure as well as the spiral case and stand ring supporting structure shall be sufficient.

7.6.12 The elevation of each floor in the main powerhouse shall meet the following requirements.

a) The requirements of the layout of the unit and auxiliary equipment, and the installation, overhaul, operation, maintenance, structural dimension and building space shall be met.

b) The installation elevation of the turbine shall be determined by technical and economic consideration according to the unit characteristics provided by the manufacturer, the turbine static suction head and the minimum downstream tail water level during the operating period of the hydropower plant, combined with the topographical and geological conditions of the powerhouse.

c) The ground elevation of the turbine floor shall be determined according to the section size of the spiral case inlet as well as the minimum thickness of the concrete structure at the top of the spiral case.

d) The ground elevation of the generator floor shall meet the layout requirement of the generator floor, and the influence of the equipment layout on the turbine floor as well as the layout of bus cables and the downstream water level shall also be considered.

e) If the space of the main powerhouse is enough, the cable floor may also be arranged below the generator floor; its net clearance shall meet the requirements of the laying of the main outgoing lines and cables, operation maintenance and fire control of the generator.

f) The roof elevation shall be determined according to the roof type and the structural dimensions, and it shall meet the requirements of installation and overhaul of the crane components, ceiling installation of the powerhouse, the layout of the lighting facilities and thermal insulation.

7.6.13 The layout of the tailrace platform shall meet the following requirements.

a) The width of the tailrace platform shall meet the requirements of the structure size of the tail lock and hoist, gate lifting, mobility, downstream flood control facilities and fire control.

b) The length of the tailrace platform may be determined according to the requirements of the operation of the hoist and the overhaul of the gate.

c) With regard to the powerhouse with a relatively long draft tube, the main transformer, switchyard or auxiliary powerhouse may be laid out on the tailrace platform; if the length of the draft tube needs to be increased for this purpose, it shall be elaborated and justified with the technical and economic consideration.

7.6.14 The layout of the control room shall be determined in line with the following principles.

a) It shall be convenient for operation and maintenance management, and convenient for transiting by stages and saving cables. The influence of vibration, noise and magnetic field should be avoided.

b) Its elevation may be equal to or slightly higher than the elevation of the generator floor. When the control room is higher than the generator floor, the mobility between them shall be convenient.

c) When the control room is arranged in the remote centralized control centre, the transition duty room may be arranged in the auxiliary powerhouse.

d) The auxiliary powerhouse for high noise equipment such as the air compressor and the ventilation equipment should not be laid out around the control room.

e) Effective measures for preventing unit vibration shall be implemented for the control room built on the tailrace platform.

f) The position and orientation with good natural ventilation and lighting conditions should be selected.

g) At least two inlets/outlets shall be arranged.

h) Complete safety and fire control facilities shall be arranged.

7.6.15 The auxiliary powerhouse area and the internal layout shall be determined according to the requirements of layout, maintenance, test and management of the electromechanical equipment, combined with the specific conditions of the powerhouse.

7.6.16 The strength of all structural components in the powerhouse shall be calculated, and the stability of the high-shelf compression components shall be further examined. The crane girder, powerhouse framework and components that need to control deformation values shall be calculated for deformation. For the parts of substructures that bear water pressure and the parts of super structures that need to be controlled crack width when being used, the crack width shall be calculated; and for the parts that directly bear vibration load, a dynamic calculation shall be conducted as well.

7.6.17 The tail race channel/tunnel shall be arranged in accordance with the specific conditions of the power plant in line with the following principles.

a) The operation conditions of the unit, the topographic conditions, the flow direction of the river, the flood releasing, the sand flushing and the influence of other structures shall be considered. Protective measures shall be applied for possible scouring or siltation areas.

b) The influence of riverbed change caused by the flood releasing and the downstream cascade backwater shall be considered

7.7 Engineering safety monitoring

7.7.1 Safety monitoring facilities shall be installed for hydraulic structures according to their importance, types, structural features and geological conditions. The items to be monitored should be selected according to Table 3.

Table 3 — Safety monitoring items for main hydraulic structures

Type of structure	Concrete dam & stone masonry dam	Earth-rock dam	Riverbed powerhouse & sluice dam	Tunnels	Forebay/Surge tank	Penstock	High and steep slope
Observed item	1. Upstream and downstream water levels 2. Uplift pressure 3. Seepage volume 4. Displacement and settlement 5. Deformation of expansion joint 6. Upstream and downstream scouring and deposition.	1. Upstream and downstream water levels 2. Saturation line 3. Seepage volume, seepage pressure of the dam foundation 4. Displacement and settlement	1. Upstream and downstream water levels 2. Uplift pressure 3. Displacement and settlement 4. Upstream and downstream scouring and deposition	1. Upstream and downstream water levels 2. External water pressure	1. Water level 2. Displacement	1. Stress 2. Strain 3. External water pressure 4. Displacement	1. Displacement 2. Deformation 3. Underground water level

7.7.2 The safety monitoring design shall comply with the following principles.

a) The safety monitoring system shall be able to reflect the actual operating performance of the project and the foundation during the construction period, storage period and operating period.

b) The key monitoring dam section and the general monitoring dam section shall be determined according to the dam height, geological conditions, structural features as well as the representativeness of the same type of dam; the key points shall be highlighted in the layout of the measuring points.

c) The monitoring items shall be arranged with full consideration and coordinated. The monitoring items and instruments shall be installed without effecting the safety of the project. Some important measuring points on the key monitoring section or positions may be monitored with at least two monitoring methods; the instruments for monitoring important physical quantity on key positions may be provided with the standby instrument.

d) The monitoring instrument and equipment to be selected shall be stable and reliable in performance, and suitable for long-term work in the severe environment. The measuring range and precision of the instrument shall meet the monitoring requirements. The instrument for the key monitoring items to be observed over the long term shall be easily replaced.

e) The instruments/equipment with advanced technologies should be adopted, and allowance shall be reserved for the future technical improvements.

f) The online/automatic monitoring system should be arranged, and the manual observation conditions shall be available as well.

7.7.3 The monitoring facilities shall be protected by effective measures, and be ease in construction, installed and maintained.

7.8 Concrete strength and durability

7.8.1 The concrete shall meet the strength requirements, and shall satisfy the durability requirements of low permeability, frost resistance, anti-erosion and anti-scour respectively according to the working conditions and regional climatic conditions of the structures. With regard to the large-volume concrete structure with relatively high requirements for preventing temperature cracks, the requirements for high expansion and low heat properties shall be proposed in the design, and low heat cement should be selected or the appropriate admixture and additive should be added.

7.8.2 The density of the concrete shall be determined by testing. If no test data are available, the density may be taken as 24 kN/m^3 for plain cement concrete; and 25 kN/m^3 for reinforced cement concrete.

7.8.3 Permanent hydraulic concrete structures shall meet the durability requirements. The corresponding durability requirements may be put forward according to the environmental category of the structure. The durability requirement may not be required for temporary structures. The design service lifespan of the SHP plant is 50 years.

7.8.4 The anti-seepage grades of the concrete for the structure shall be determined according to the head, the hydraulic gradient as well as the downstream drainage conditions, water quality conditions and hazard rating of the infiltration water.

7.8.5 With regard to the structures with a frost resistance requirement, the frost resistant grades shall be selected according to the climatic regions, frost-thaw cycle times, local micro-climatic conditions of the surface, degree of moisture saturation and maintenance conditions.

7.8.6 The air entraining admixture shall be mixed into the frost-resistant concrete. The variety and quantity of cement, admixture and additive, the water-cement ratio, mix proportion and air content shall be determined through tests or selected according to the design requirements of frost-resistance of hydraulic structures. The air entraining admixture should be mixed into the concrete used in the marine environment even though there is no frost resistance requirement.

7.8.7 With regard to the concrete in contact with the corrosive medium, anti-corrosive cement shall be used, mixed with high-quality active admixture, or at the same time, the special surface coating and other protective measures. For the parts suffering from high-velocity flow cavitation erosion, measures such as reasonable structural profile, improving ventilation condition, increasing concrete density, strictly controlling the flatness of the structure surface or setting special protective surface layer shall be adopted. For the parts with sediment abrasion, hard aggregates shall be used, the water-cement ratio shall be reduced, the concrete strength grade shall be upgraded and the construction method shall be improved; wear-resistant surface protective materials or fibre concrete shall be used when necessary.

8 Hydraulic machinery, fire protection, heating and ventilation

8.1 General requirements for selection of turbine and generator

8.1.1 The type and basic parameters of the turbine shall be selected on the basis of technical and economic consideration in accordance with the hydraulic energy parameters, the layout and operating characteristics of the hydropower plant, the technical features, economic indexes, operation reliability, technical level of the design and manufacture, the transportation and in combination with the site conditions.

a) The turbine type selection shall include the following contents:

1) selection of the type and installation mode (horizontal or vertical);

2) selection of the number of units and the unit capacity;

3) selection of the rated head of the turbine;

4) selection and calculation of the basic parameters of the turbine, including the shaft power, runner diameter, rated speed, rated discharge, efficiency, static suction head and the setting elevation - for the impulse turbine, the jet diameter, number of nozzles and the static discharge head shall be selected;

5) selection of the appropriate model runner and the plotting of the turbine operating characteristic curve;

6) estimation of the overall dimensions, weight and cost of the main components of the turbine.

b) The basic information for turbine selection shall include:

1) turbine net head (including the maximum head, the minimum head and the weighted average head);

2) the operating discharge of the hydropower plant (the sum of the discharges enter into each turbine in a hydropower plant);

3) installed capacity of the hydropower plant;

4) upstream/downstream water level;

5) parameters of the power generation and water conductor systems (including the arrangement, length, pipe diameter and head losses of all water conductor systems from the water inlet for the generation to the tailwater outlet of the hydropower plant);

6) tailwater level-discharge relation curve;

7) firm output of the hydropower plant, the power weighting factor can be provided when necessary;

8) operation mode of the hydropower plant in the power system, and reservoir operation and regulation modes;

9) quality of the water passing through the turbine (including the sediment concentration through the turbine, the particle size grading, Mohr's hardness, mineral composition, PH value and water temperature);

10) meteorological conditions of the hydropower plant (including the air temperature, water temperature and relative humidity);

11) geographic position of the hydropower plant (including the sea level elevation, atmospheric pressure and gravitational acceleration of powerhouse).

8.1.2 The generator shall be selected through technical and economic consideration in accordance with the type and the parameters of the turbine and the requirements of the power system, and in combination with the parameters such as the unit output, rotating speed, unit configuration and layout determined during turbine selection. Generator type selection shall include the following consideration:

a) rated power/apparent power of the generator;

b) rated voltage of the generator;

c) rated speed;

d) runaway speed;

e) rated frequency;

f) rated power factor;

g) insulation grade;

h) exciting mode;

i) ventilation-cooling type of the generator;

j) moment of inertia of the generator (GD^2);

k) estimation of the dimensions, weight and cost of the main components of the generator.

8.2 Selection of turbine rated head

8.2.1 The rated head of turbine shall be selected through technical and economic consideration in accordance with the head variation of the hydropower plant, the regulating characteristic of the reservoir, the stable operation requirements of the unit, the operation mode of the hydropower plant in the power system and the characteristics of the power generation and water conductor systems.

8.2.2 As for the hydropower plant with the medium/high head, the rated head should be selected within the scope of 0,85 to 0,95 times the weighted average head.

8.2.3 When the rated head is close to the minimum head, its rationality and economic efficiency shall be demonstrated. With regard to the impulse turbine with high head and small variation of the reservoir water level, the minimum head may be used as the rated head of the turbine.

8.3 Selection of turbine type

8.3.1 The turbine type shall be selected within the operation head range in accordance with the basic principles in 8.1. See Table 4 for the common turbine types and the applicable head and specific speed range.

Table 4 — Turbine types and the applicable head and specific speed range

<table>
<tr><th colspan="4">Turbine type</th><th rowspan="2">Applicable head range [a]
(m)</th><th rowspan="2">Applicable specific speed [b]
n_q
(r/min)</th></tr>
<tr><th>Classification in accordance with the energy conversion mode</th><th>Classification in accordance with the water flow direction</th><th colspan="2">Classification in accordance with the structural feature</th></tr>
<tr><td rowspan="12">Reaction turbine</td><td rowspan="12">Axial-flow turbine</td><td colspan="2">Bulb turbine</td><td rowspan="4">2~30</td><td rowspan="4">83~287</td></tr>
<tr><td colspan="2">Shaft-extension-type tubular turbine</td></tr>
<tr><td colspan="2">Pit turbine</td></tr>
<tr><td colspan="2">Straight flow turbine</td></tr>
<tr><td colspan="2">Propeller turbine</td><td rowspan="3">5~60</td><td>83~178</td></tr>
<tr><td colspan="2">Kaplan turbine</td><td rowspan="2">83~110</td></tr>
<tr><td colspan="2">Semi-Kaplan turbine (5-6 blades)</td></tr>
<tr><td rowspan="4">Francis Turbine</td><td>Slow runner</td><td>160~800</td><td>17~40</td></tr>
<tr><td>Normal runner</td><td>50~200</td><td>40~68</td></tr>
<tr><td>Quick runner</td><td>30~70</td><td>67~100</td></tr>
<tr><td>Extra-quick runner</td><td>20~50</td><td>97~150</td></tr>
<tr><td colspan="2">PAT
Pump as turbine</td><td>10~150</td><td>12~96</td></tr>
</table>

a The applicable head range is the parameter under normal conditions. The selection of small turbine can be determined through comprehensive comparison according to the specific situation and the special requirements of the different projects. The applicable head range for the various types of units in the same head section can be appropriately broadened.

b Specific speed, n_q [r/min], is calculated as follows:

$$n_q = \frac{n.Q^{(1/2)}}{H^{(5/4)}}$$

where

n is the speed, in r/min;

Q is the discharge, in m^3/s;

H is the head, in m.

Another way of expressing specific speed is n_s where $n_s = 3{,}65\ n_q$ and is calculated as follows:

$$n_s = \frac{n.P^{(1/2)}}{H^{(5/4)}}$$

where

n is the speed, in r/min;

P is the power, in HP;

H is the head, in m.

Table 4 *(continued)*

Turbine type			Applicable head range [a] (m)	Applicable specific speed [b] n_q (r/min)
Classification in accordance with the energy conversion mode	**Classification in accordance with the water flow direction**	**Classification in accordance with the structural feature**		
Impulse turbine	Pelton turbine	1~2 jet	60~1300	1~12
		3~4 jet		5~17
	Inclined-jet turbine (Turgo turbine)	1~4 jet	10~300	5~19
	Cross-flow turbine		5~200	12~96

[a] The applicable head range is the parameter under normal conditions. The selection of small turbine can be determined through comprehensive comparison according to the specific situation and the special requirements of the different projects. The applicable head range for the various types of units in the same head section can be appropriately broadened.

[b] Specific speed, n_q [r/min], is calculated as follows:

$$n_q = \frac{n.Q^{(1/2)}}{H^{(5/4)}}$$

where

n is the speed, in r/min;

Q is the discharge, in m^3/s;

H is the head, in m.

Another way of expressing specific speed is n_s where $n_s = 3{,}65\ n_q$ and is calculated as follows:

$$n_s = \frac{n.P^{(1/2)}}{H^{(5/4)}}$$

where

n is the speed, in r/min;

P is the power, in HP;

H is the head, in m.

8.3.2 When there are two applicable turbine types under the same head, the selection shall be made by technical and economical consideration in the respect of the technical characteristic parameters, the economic indicators, operational reliability and the design and manufacturing difficulty.

8.3.3 The layout of the vertical shaft and horizontal shaft Francis turbines and impulse turbines shall be combined with the single unit capacity, the diameter of the runner, and the appropriate speed and plant layout for a comprehensive comparison.

8.4 Selection of basic parameters of the reaction turbine

8.4.1 The basic parameters of the reaction turbine shall be selected after the primary selection of the unit capacity, rated head and model runner; the main parameters include runner diameter, rated speed, rated discharge, rated efficiency, rated power, static suction head, maximum runaway speed, maximum head, minimum head, design head and the weighted average efficiency.

8.4.2 A reasonable scheme of the basic parameters of turbine shall be selected from a number of different combinations of the parameters by technical and economic consideration combined with the power plant layout, the actual topography and geological conditions, the operating water head range and the reservoir regulation characteristics, as well as the technical characteristics, economic indicators, operational reliability, and design and manufacturing technology level.

8.4.3 The setting elevation of the turbine shall meet the requirements of the static suction head and the corresponding tailwater level under various operating conditions, and shall comply with the requirements that the minimum submerged depth of the upper edge of the draft tube (or the tailrace tunnel, excluding the tailrace tunnel with sloping ceiling) outlet shall not be less than 0,3 m to 0,5 m. The installation elevation shall be determined by technical and economic consideration on the basis of the actual topographic and geological conditions of the project, the layout of the plant and other factors.

8.4.4 The turbine runner diameter shall be calculated by Formula (2).

$$D_1 = \sqrt{\frac{N_\mathrm{f}}{9{,}81 Q_1^{'} H_\mathrm{sj}^{1{,}5} \eta_\mathrm{T} \eta_\mathrm{f}}} \tag{2}$$

where

D_1 is the nominal diameter of runner, in m;

N_f is the rated power of generator, in kW;

$Q_1^{'}$ is the unit discharge under rated conditions, in m^3/s;

H_sj is the rated head, in m;

η_T is the prototype turbine efficiency;

η_f is the rated efficiency of generator.

8.4.5 The rated speed shall be calculated by Formula (3):

$$n_\mathrm{r} = \frac{n_1^{'} \sqrt{H_\mathrm{pj}}}{D_1} \tag{3}$$

where

n_r is the rated speed, in r/min;

$n_1^{'}$ is the unit speed, in r/min; 1 $n_{10}^{'}$ to 1,05 $n_{10}^{'}$ is taken for Francis turbine; 1,1 $n_{10}^{'}$ is taken for high specific speed axial-flow turbine; $n_{10}^{'}$ is the optimal unit speed in r/min;

H_pj is the weighted average head, in m.

Turbine speed should match to nearest synchronous speed of generator which is calculated by Formula (4):

$$n_\mathrm{r} = \frac{60 f_\mathrm{r}}{p} \tag{4}$$

where

n_r is the rotating speed, in r/min;

f_r is the grid frequency, in Hz;

p is the number of pole pairs, 2p refers to the number of poles.

See Table 5 for the standard rotational speed of generator.

Table 5 — Standard rotational speed of generator

Number of poles	Frequency		Number of poles	Frequency	
	50 Hz	60 Hz		50 Hz	60 Hz
2	3 000	3 600	16	375	450
4	1 500	1 800	18	333	400
6	1 000	1 200	20	300	360
8	750	900	22	272	327
10	600	720	24	250	300
12	500	600	26	231	277
14	428	540	28	214	257

8.5 Selection of basic parameters of the impulse turbine

8.5.1 The basic parameters of the impulse turbine shall be selected after the primary selection of the unit capacity, rated head and model runner; the main parameters include the rated head, rated speed, rated discharge, rated power, pitch diameter, jet diameter, ratio of runner diameter to jet diameter (m-value), bucket numbers, rated efficiency, maximum head, minimum head, design head, runaway speed and static discharge head. The selection of the basic parameters of the turbine shall be determined through technical and economic consideration.

8.5.2 The number of nozzles of the impulse turbine should be 1, 2 or 4; the number of nozzles shall be determined with consideration given to the arrangement of the nozzles to avoid the mutual interference of the jet flow.

8.5.3 For ensuring the relatively high efficiency of the turbine, m-value should be selected in the range of 10 to 20; when selecting the m-value, the manufacturing mode of the runner and the strength of the bucket shall be considered; usually, the large value should be taken for the high head and the small value should be for the low head.

8.5.4 The static discharge head of the impulse turbine shall be selected to ensure the safe and stable operation of the turbine, avoid the influence of the tailwater surge and keep sufficient ventilation height for the tailrace at the maximum tailwater level and under any power generating condition of the hydropower plant. The static discharge head shall be the diameter ($1D_1$ to $1{,}5D_1$) of the runner pitch circle. The horizontal shaft unit should take a small value, and the vertical shaft unit should take a large value. When determining the static discharge head, the necessary ventilation height shall be ensured, and the ventilation height should be no less than 300 mm.

8.5.5 The runner diameter and m-value shall be calculated according to Formula (5) and Formula (6):

$$D_1 = \frac{(39\sim 40)\sqrt{H_{sj}}}{n_r} \qquad (5)$$

$$m = \frac{D_1}{d_0} \qquad (6)$$

where

D_1 is the pitch diameter of the bucket, in m;

m is the ratio of the runner diameter to the jet diameter.

The m-value should be in the range of 10 to 20. Small value should be taken for the low head and large value should be taken for the high head.

For turgo impulse and cross flow (Banki) the factor in Formula (5) may be taken as 35 and 40 respectively.

8.6 Unit transient performance analysis

8.6.1 The calculations for turbine transient performance shall be conducted according to the main electrical connection mode of the hydropower plant, the power grid requirements, the type and parameters of the water conductor system of the hydropower plant, the characteristics and parameters of the turbine generator units as well as the operating conditions.

8.6.2 As for the hydropower plant with bifurcated/trifurcated penstocks, the maximum speed increase rate of the units and the maximum pressure increase rate at the end of the spiral casing shall be calculated according to the number of units connected to the main penstock and the main electrical connection mode, as well as the number of units that may be simultaneously perform load rejection.

8.6.3 The guaranteed value of the maximum speed increase rate of the unit during the load rejection shall be selected according to the following different circumstances.

a) The guaranteed value should be less than 50 % when the unit capacity accounts for a large proportion of the total capacity of the power system or the unit is responsible for frequency modulation.

b) The guaranteed value should be less than 60 % to 65 % when the proportion of the unit capacity to the total capacity of the power system is not large, or the unit is not responsible for frequency modulation.

c) The maximum speed increase rate of the tubular turbine unit should be less than 65 %.

d) The maximum speed increase rate of the impulse turbine unit should be less than 30 %.

8.6.4 In case of load rejection, the guaranteed value of the maximum pressure increase rate at the end of the spiral case (in front of the movable guide vane of the tubular turbine unit) shall be selected in accordance with the following circumstances.

a) The guaranteed value should be 70 % to 100 % if the rated head is less than 20 m.

b) The guaranteed value should be 70 % to 50 % if the rated head is 20 m to 40 m.

c) The guaranteed value should be 50 % to 30 % if the rated head is 40 m to 100 m.

d) The guaranteed value should be 30 % to 25 % if the rated head is 100 m to 300 m.

e) The guaranteed value should be less than 25 % if the rated head is more than 300 m.

8.6.5 When the guaranteed value of pressure increase rate and speed increase rate cannot meet the design requirements, the following measures may be taken:

a) revise the rule of the guide vane closing;

b) increase the moment of inertia of generator (micro hydro power plant may add flywheel);

c) set up pressure regulating valve or surge tank;

d) revise the layout or dimensions of the penstocks.

8.6.6 In case of load rejection, the maximum vacuum guaranteed value at the entrance section of the draft tube shall not be greater than 0,08 MPa.

8.7 Turbine governing system

8.7.1 Each unit shall be equipped with a governing system composed of governor, oil pressure unit and other auxiliary equipment.

8.7.2 The operating capacity of the governor shall be selected so that the unit can be reliably controlled under the maximum head and the maximum discharge and be started and stopped in accordance with the time required by the calculation for turbine transient performance. The operating capacity of the governor shall have sufficient reserve allowance.

8.7.3 In order to ensure the safety of power plant equipment and users when disconnecting with the system, the automatic microcomputer-based turbine governing system shall be equipped for the unit with the possibility that operating within an isolated grid.

8.7.4 As for the small and micro units without the frequency regulation task and with no need to guarantee the auxiliary power when the unit breaks down, the electric actuator or hydraulic actuator may be used, but it shall ensure that the unit can stop safely and reliably when it breaks down. As for the hydropower plant without the DC operating power supply, the actuator shall be equipped with the emergency shutdown device for power failure.

8.7.5 The high oil pressure (10 MPa and above) bladder-type energy accumulator and the external servomotor should be adopted.

8.7.6 The operating capacity of the governor for the medium and small sized Francis and axial-flow fixed blade propeller turbine may be calculated by Formula (7):

$$A = KQ\sqrt{H_{max} D_1} \tag{7}$$

where

A is the operating capacity of servomotor, in N·m;

K is the coefficient, value range: 250 to 300;

Q is the rated discharge of unit, in m^3/s;

H_{max} is the maximum head, in m;

D_1 is the diameter of the turbine runner, in m.

8.7.7 The control system of the governor shall have the following basic auxiliary functions: frequency tracking (or fast synchronization), fault detection and treatment, artificial dead band, non-disturbance manual and automatic switchover, auxiliary test and partial fault-tolerance.

8.8 Turbine main inlet valve

8.8.1 For the hydropower plants where several turbines are supplied by one single penstock, the main inlet valve shall be set in front of each turbine.

8.8.2 For the unit water conductor system of the dam toe hydropower plant with the short penstock, or the low head unit water conductor system of the runoff hydropower plant or the river bed hydropower plant, the main inlet valve may not be equipped in front of the turbine.

8.8.3 The main inlet valve shall be selected based on the comprehensive analysis of the technical, economic and operational safety and reliability, according to the water head, the maximum transient pressure, the rated discharge of turbine, the diameter of the spiral case inlet and the sediment characteristics.

8.8.4 The butterfly valve, spherical valve and gate valve are often used as the main inlet valve of the turbine. When the maximum head is lower than 250 m, the butterfly valve should be selected. When the maximum head is higher than 250 m (inclusive), the spherical valve or the gate valve should be selected. The butterfly valve used as the main inlet valve of the turbine shall be of the eccentric structure, and the valve body shall be marked with arrows indicating the water flow direction. Full-size fixed spherical valve shall be used and should be arranged horizontally. The gate valve shall be of full-size structure and the valve shaft shall be installed vertically.

8.8.5 The main inlet valve shall be able to be closed in flowing water, and the closing time shall not exceed the time allowable for the continuous operation of the unit under the maximum runaway speed. The main inlet valve shall be able to be opened normally and not produce harmful vibration when the pressure difference between both sides is not greater than 30 % of the maximum static water pressure.

8.8.6 The design pressure of the main inlet valve shall be the maximum transient pressure, in MPa. The nominal diameter of the butterfly valve may be calculated by Formula (8) and Formula (9):

$$D_f = \frac{D_0}{\sqrt{\alpha}} \tag{8}$$

$$\alpha = 1 - 0{,}0687\sqrt[3]{H_{max}} \tag{9}$$

where

D_f is the diameter of the butterfly valve, in m;

D_0 is the diameter of spiral case inlet section, in m;

α is the coefficient related to the head;

H_{max} is the maximum static head of the hydropower plant, in m.

8.9 Cooling water and drainage system

8.9.1 The water supply source for cooling and sealing shall reasonably be selected according to the requirements of the water volume, water pressure, water temperature and water quality, and the specific conditions of the power plant. Water may be taken from reservoirs, penstock, power plant tail water or other water sources and then passed through a filtration system before feeding to bearing and generator coolers or shaft sealing arrangement.

8.9.2 The water supply mode shall be determined according to the range of water head of the power plant; when the minimum head is lower than 15 m, water should be supplied by pump; when the net head is from 15 m to 100 m, water should be supplied by gravity flowing or gravity flowing with pressure reduction; when the net head is higher than 100 m, water should be supplied by gravity flowing with pressure reduction and others.

8.9.3 The water supply system shall be able to be operated automatically.

8.9.4 The main shaft sealing water of the turbine should be provided with standby water supply which can be put into use automatically.

8.9.5 When water is supplied by pump, the standby water pump shall be equipped.

8.9.6 The water supply system shall be equipped with the water filter. When the water filter is working, water supply system shall not be interrupted. Water quality of bearing lubrication water and main shaft sealing water shall meet the requirements of the unit.

8.9.7 The water drainage system shall be set up respectively for unit maintenance drainage and plant leakage drainage, and the following requirements shall be met.

a) Two drainage pumps shall be installed for the unit maintenance, and the total displacement shall be guaranteed to exclude the total displacement of one unit for maintenance within 4 hours to 6 hours.

b) There shall be no less than two drainage pumps for the leakage drainage sump in the plant, one of which shall be set aside. The drainage pumps shall be automatically controlled with the change of water level of the drainage sump.

8.9.8 The outdoor drainage system within the plant area shall be an independent system, which shall not feed water into the drainage sump or the drainage gallery in the plant.

8.9.9 The leakage drainage from the power plant should not be directly discharged into the river without treatment.

8.10 Oil system

8.10.1 A turbine oil system may be set up according to the needs of the hydropower plant, and oil treatment and storage equipment shall be equipped.

8.10.2 Insulation oil system may not be set.

8.10.3 The volume of the turbine oil tank shall meet the requirements of oil storage, oil replacement during overhaul and oil purification. The volume of the turbine oil tank should be 110 % of the oil consumption of the unit with the largest capacity.

8.10.4 The oil treatment equipment shall include the oil pump and oil purification equipment, and the types, capacity and quantity of which may be determined according to the oil consumption of the hydropower plant.

8.10.5 A central oil service system should be established for the cascade hydropower plants or a group of hydropower plants. The central oil service system shall be equipped with the oil storage, oil treatment and oil purification equipment. The configuration of the oil system for the hydropower plant equipped with central oil service system shall be simplified.

8.11 Compressed air system

8.11.1 The medium pressure and low pressure compressed air system may be set up in the powerhouse according to the needs of the hydropower plant.

8.11.2 The pressure of the medium pressure compressed air system for the inflation of the oil pressure device shall be determined according to the rated operating pressure of the oil pressure device; two air compressors shall be equipped, one for use and one for standby and air tank shall be equipped. The volume of the air tank may be determined according to the air compensation for the pressure oil tank. The rated operating pressure of the air tank should be 0,2 MPa to 0,3 MPa higher than the rated operating pressure of the pressure oil tank. The air tank shall be fitted with the safety valve, pressure gauge and blow-down valve.

8.11.3 The pressure of the low pressure compressed air system used for unit braking, overhaul and maintenance, and sealing of the circular band of the turbine main shafts shall be from 0,7 MPa to 0,8 Mpa; the braking air for the unit shall meet the following requirements.

a) The braking air of the unit should be equipped with exclusive air tank and exclusive air supply pipe.

b) The total volume of the air tank for unit braking shall be determined according to the total air consumption of the units to be braked simultaneously.

c) The capacity of the air compressor shall be determined in accordance with the air consumption of the units to be braked simultaneously and the time of restoring working pressure of the compressed air tank. The time of restoring working pressure of the compressed air tank may be from 10 min to 15 min.

d) The braking air of the unit should be supplied with the standby air compressor or other standby air source.

8.11.4 The rated working pressure of the air compressor should be 0,1 MPa to 0,3 MPa higher than the rated working pressure of air tank.

8.12 Hydraulic monitoring system

8.12.1 The hydraulic monitoring system shall meet the requirements for safe, reliable and economical operation and automatic control of the turbine generator unit.

8.12.2 The hydropower plant should be equipped with the conventional instrumentation for measurements parameters viz the upstream water level, downstream water level, surge-chamber water level, hydropower plant head, pressure difference between the front and back of the trash rack as well as the reservoir water temperature. The unit should be provided with routine measurement instruments such as pressure at the intake of the spiral case, head cover pressure, pressure at the intake of the draft tube as well as the cooling water pressure of the unit, while the selective measurement items may be provided as well, such as the flow passing through the unit, the pressure fluctuation of the turbine, the unit efficiency, unit vibration, runout of the unit and the pressure (vacuum) in the draft tube.

8.12.3 The hydraulic monitoring system shall be designed and arranged in combination with the automatic monitoring system of the hydropower plant.

8.13 Selection of lifting equipment

8.13.1 Cranes or other hoisting equipment shall be installed in the powerhouse of the hydropower plant. Single-trolley or double-trolley bridge cranes may be used. The rated lifting weight shall be determined according to the total weight of the heaviest object to be lifted plus any hoisting tools and with reference to the standard lifting capacity of the crane series. The crane span may be selected according to the standard crane span. The lifting height and speed of the crane shall meet the requirements of installation and overhaul of units.

8.13.2 For the hydropower plant with a Gas Insulated Switchgear (GIS) room, a crane shall be installed for the installation and overhaul of GIS room.

8.13.3 The operation mode of the crane may be in the form of cab, ground wire control or ground wireless remote control.

8.14 Fire protection

8.14.1 The fire hazard classification and fire resistance ratings of the powerhouse are classified in accordance with the standards of the country. The fire protection of the power plant and unit equipment follow the national fire protection standards.

8.14.2 There shall be at least two evacuation exits for the main and auxiliary powerhouse of the hydropower plant. On the generator floor and the floors below, the distance between the furthest indoor workplace to the nearest safe evacuation exit on this floor shall not exceed 60 m.

8.14.3 A 100 % oil storage pit or a 20 % oil storage pit and a common oil storage tank shall be provided for the main oil-immersed transformer with single oil capacity over 1 000 kg and the other oil filling equipment.

8.14.4 Power cables and control cables shall be laid in layers. The cables laid in layers shall be separated by clapboards with fire endurance not less than 0,5 hour.

8.14.5 Every 100 m of cable tunnel and ditches shall be equipped with a fire-proof partition. Closure and partition measures shall be implemented for the through-wall.

8.14.6 Automatic fire extinguishing system such as water spray or CO_2 spray shall be equipped for the turbine generator unit with a unit capacity not less than 12,5 MVA and water spray system for the indoor main oil-immersed transformer with a unit capacity not less than 12,5 MVA.

8.14.7 The powerhouse shall be equipped with smoke exhaust facilities and shall be integrated with the ventilation system.

8.14.8 Natural water source, specific fire water ponds or fire water pumps may be used as the water supply sources for in-plant fire protection. The water supply for fire protection may be incorporated with the living and production water supply system. The quality, pressure and volume of supplied water shall meet the requirements of fire protection purposes.

8.14.9 Firefighting apparatuses shall be powered in accordance with the Grade 2 load with an independent power supply circuit. The control equipment for the firefighting apparatuses shall be installed in the central control room. When the water is supplied with the fire water pump, the starting device for the firewater pump should be set in the fire cabinet.

8.14.10 The emergency lighting and evacuation signs shall be provided in the evacuation exit, staircases, exits and fire pump house of the powerhouse.

8.14.11 The automatic fire alarm device shall be installed in the hydropower plant.

8.15 Heating and ventilation

8.15.1 The heating and ventilation patterns of the hydropower plant shall be determined according to the local meteorological conditions, the powerhouse type and the requirements for air parameters in production sites and shall comply with the relevant national provisions.

8.15.2 Natural ventilation should be adopted for the generator hall, erection bay and auxiliary rooms of the surface powerhouse. When the natural ventilation cannot meet the requirements of indoor air parameter, the natural-mechanical mixed ventilation, mechanical ventilation and partial air conditioning may be adopted.

8.15.3 If the pipeline ventilation is adopted for the generator, the hot air shall be directed outside the powerhouse.

8.15.4 The oil tank room and the oil treatment room shall be equipped with separate ventilation system. The air outlets of the ventilation system shall be 1,5 m higher than the roof.

8.15.5 The ventilation rate of the GIS room shall be 8 times per hour, and the air inlet shall be set in the lower part of the room.

8.15.6 The heating device shall be equipped when the indoor temperature of the main and auxiliary powerhouses is lower than 5 °C.

8.15.7 Necessary ventilation facilities shall be installed in the gallery at the bottom of the dam.

8.16 Repair and maintenance equipment

8.16.1 The mechanical repair and maintenance equipment may be configured according to the overhaul content of electro-mechanical equipment, external transportation and outsourcing fabrication conditions, etc.

8.16.2 A central repair and maintenance workshop should be set up for cascade hydropower plants and a group of hydropower plants.

8.17 Arrangement of hydraulic machinery equipment

8.17.1 Hydraulic machinery and electrical equipment should be arranged separately. The length and width of the unit section of the main powerhouse shall be determined according to the size of the unit as well as the passageway, governor, oil pressure device, main inlet valve and electrical panel/cabinet, and in combination with the requirements for installation, overhaul, operation, transportation and civil engineering design. The width of the main powerhouse shall also meet the requirement of the size of the crane lifting components and the main inlet valve. The layout of the powerhouse shall be designed with full consideration given to the comprehensive requirements of ecology and environmental protection.

8.17.2 The lifting height in the main powerhouse shall meet the following requirements:

a) requirements for the integral lifting of the generator rotor with the shaft;

b) requirements for assembling the turbine with the shaft sleeve for integral lifting;

c) requirements for in-plant maintenance of the main transformer if necessary;

d) requirements to turn over the guide vane and other parts of the bulb tubular unit;

e) the distance between parts to be lifted by the crane and fixed objects shall be neither less than 0,3 m in the vertical direction nor less than 0,4 m in the horizontal direction.

8.17.3 The area of the erection bay shall be determined according to the needs of the extended overhaul of one unit. The main parts of the unit shall be arranged within the working range of the crane hook and shall meet the following requirements:

a) requirements for hoisting order of lifting parts during installation and overhaul;

b) the net distance between the large parts of the unit and between the large parts of the unit and the walls (columns) and the fixed equipment shall be from 0,8 m to 1,0 m;

c) requirements for in-plant loading and unloading by vehicles.

8.17.4 Turbine oil room may be located in the powerhouse; insulation oil tank should be located outside the powerhouse; oil treatment room shall be arranged near the tank room.

8.17.5 Other auxiliary machinery shall be arranged to facilitate the installation, operation and maintenance of the equipment.

9 Electrical system

9.1 Connection of the hydropower plant to the power system

The power connection point, transmission voltage, number of outlet transmission lines, transmission capacity, operation mode and the type of connection to the grid shall be determined in light of the characteristics of the hydropower plant and the requirements of the power system.

9.2 Main electrical connection wiring

The type, characteristic and applicability of the main electrical connection of the SHP plant are recommended in Table 6 and Table 7.

Table 6 — Voltage connection of generator

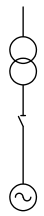
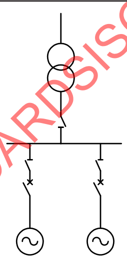
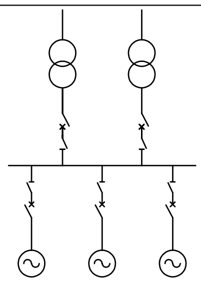
Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Unit connection		1. The capacity of the main transformer is as the same as that of the generator, and the scope of the fault is minimal. 2. The connection is simple, clear and flexible. 3. Minimum generator voltage equipment is required, and the layout is simple. 4. The relaying protection is simple. 5. The number of the main transformers and high-voltage electrical equipment is increased.	Applicable to the power plants with high reliability requirements, or applicable to the power plants constructed in phases.
Expanded unit connection		1. Two (or more than two) units connected to one main transformer, and the scope of the fault is relatively large. 2. The connection is simple, clear, and easy to operate and maintain. 3. The number of outlet circuits from the high-voltage side of the main transformer is reduced.	1. Applicable to the power plants that play important roles in the grid, with 4 or more units. 2. Applicable to the ordinary power plants with a relatively small near-zone load.
Single-bus connection		1. There is a small number of main transformers. 2. There are more components for generator switchgear installation. 3. When the bus or the isolating switch connected to the bus fails or is repaired, the power of entire plant will be cut off.	Applicable to the ordinary SHP plants with a relatively large near-zone load.

Table 6 *(continued)*

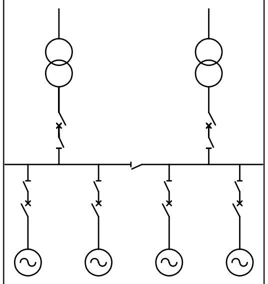
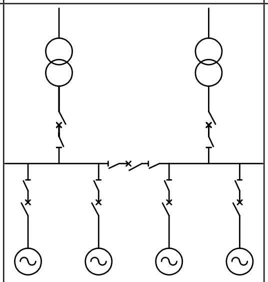
Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Sectional single-bus connection with isolating switch		1. When any section of the bus and the isolating switch connected to it fails or is repaired, the plant only needs to power off for a short time, and after the sectional isolating switch is opened, the unit connected to another section of the bus may resume to send electricity to the grid. 2. When the sectional isolating switch fails or is repaired, the entire plant will be cut off.	The use of the section isolating switch may lead to loaded misoperation, so it is rarely used.
Sectional single-bus connection with circuit breaker		When any section of the bus and the isolating switch connected to it fails or is repaired, the unit connected to another section of the bus may continue to send electricity to the grid.	1. Applicable to the SHP plants that play important roles in the grid. 2. Applicable to the power plants which have many units and near-zone load.

Table 7 — Boosted voltage side connection

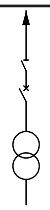
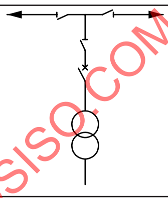
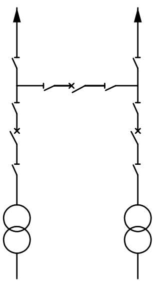
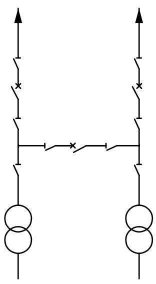
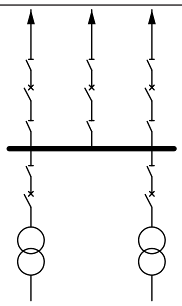
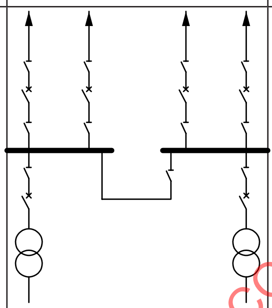
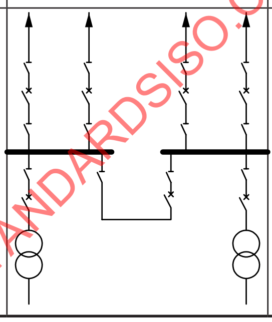
Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Transformer- line unit connection		1. The connection is the simplest, and the least equipment is needed. 2. When the line fails or is repaired, the main transformer will stop working, and vice versa.	Applicable to the power plant with one single outlet circuit.
T-type connection		The advantages and disadvantages are the same as those of the transformer-line unit connection.	Applicable to the power plant which is not important on the power grid and there is a nearby transmission line.
Outer bridge connection		1. The connection is simple, and the number of high-voltage circuit breakers is less (namely the number of inlet and outlet circuits minus one). 2. When the one of the main transformer fails or is inspected or repaired, the operation of the line and another main transformer will not be affected. 3. When the one of the outlet circuit fails or is inspected or repaired, the output of half the power of the plant will be suspended, and after the isolating switch is opened, all the power may be sent out by another outlet circuit.	1. Applicable to the power plants with two inlet and outlet circuits respectively, and the main transformer switching on and off frequently. 2. When there is crossing power, the outer bridge connection should also be adopted.

Table 7 *(continued)*

Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Inner bridge connection		1. The connection is simple, and the number of high-voltage circuit breakers is less (namely the number of inlet and outlet circuits minus one). 2. When the outlet circuit fails or is inspected or repaired, the operation of the main transformer will not be affected. 3. When the one of the main transformer fails or is inspected or repaired, an outlet circuit will be cut off temporarily, and after the main transformer isolating switch is opened, half the power of the power plant may be sent out by the two outlet circuits.	Applicable to the power plants with two inlet and outlet circuits respectively, fewer annual utilization hours, and the main transformer frequently switching on or off or the outlet line is long.
Single-bus connection		1. Each circuit of the inlet or outlet is equipped with an independent circuit breaker. 2. When the bus or the isolating switch connected to it fails or is inspected or repaired, the entire plant will be powered off.	Applicable to the hydropower plants that are not important in the power system and have less requirement for the continuity of power supply. The voltage of the outlet circuit is 35(33) kV and above, and the total number of outlet circuits is not more than 3 to 5.
Sectional single-bus connection with isolating switch		When the bus or the connected equipment is being inspected and repaired or fails, the entire plant will be powered off; after the sectional isolating switch is opened, another section of the bus may supply the power. However, when the sectional isolating switch is being inspected and repaired or fails, the entire plant will be power off.	Same as the single-bus connection.
Sectional single-bus connection with circuit breaker		When the bus or connected equipment is being inspected and repaired or is faulted, only one section of the bus and the circuit connected will be powered off.	Applicable to the power plants that the voltage of the outlet circuit is 35(33) kV and above, and the total number of outlet circuits is not more than 6.

9.3 Selection of the main transformer

9.3.1 The capacity of the main transformer shall be higher than the generating capacity of the connected generator. When restricted by the transportation conditions, two three-phase transformers with small capacity may be selected and used in parallel.

9.3.2 The parallel operation shall meet the following requirements:

a) the winding connection is the same;

b) the rated voltage of the primary and secondary winding are the same (with the same transformation ratio);

c) the per unit impedance voltage is the same.

9.3.3 Under the circumstance that two types of high voltage are used to transmit electricity to the grid, if the transmission capacity of the medium-voltage side accounts for more than 20 % of the capacity of the main transformer, a three-winding transformer or an auto transformer may be adopted; if one of the two types of the voltage is neutral and not directly grounded, a three-winding transformer shall be selected

9.3.4 The fully enclosed oil-immersed transformer should not be recommended if the environment temperature changes greatly.

9.3.5 Under the circumstance that the limit of the temperature rise is satisfied, the oil-immersed natural air cooling mode should be selected.

9.4 Selection of high-voltage electrical equipment

9.4.1 The selection of the high-voltage electrical equipment shall meet the following requirements:

a) The requirements on normal operation, inspection, repair, short circuit and overvoltage.

b) The high-voltage electrical equipment may be selected in accordance with the items given in Table 8.

Table 8 — Items for selection of high-voltage electrical equipment

No.	Item	Rated voltage (kV)	Rated current (A)	Rated capacity (kVA)	Rated breaking current (kA)	Stability of short circuit current	
						Thermal stability	Dynamic stability
1	Circuit breaker	✓	✓		✓	✓	✓
2	Isolating switch	✓	✓			✓	✓
3	Current transformer	✓	✓			✓	✓
4	Voltage transformer	✓					
5	Fuse	✓	✓		✓		
6	Load switch	✓	✓			✓	✓
7	Current-limiting reactor	✓	✓			✓	✓
8	Arc suppression coil	✓	✓	✓			
9	Post insulator	✓					✓
10	Wall bushing	✓	✓			✓	✓

c) The ambient temperature at the installation position of the electrical equipment may be selected in accordance with Table 9. When the ambient temperature at installation position is higher than +40 °C(Max limit +60 °C), the rated current shall be reduced by 1,8 % for every 1 °C that the temperature rises.

Table 9 — Ambient temperature for selection of electrical equipment

Installation place	Maximum ambient temperature (°C)	Minimum ambient temperature (°C)
Outdoor	Annual maximum temperature	Annual minimum temperature
Indoor reactor	Maximum ventilation temperature according to the ventilation design	
Others (indoor)	Ventilation design temperature, or average maximum temperature in hottest month plus 5 °C	

9.4.2 The selection of the high-voltage circuit breaker shall meet the following requirements.

a) The vacuum or Sulfur Hexa-Fluoride (SF6) circuit breaker may be selected for the circuit of 3 kV or above.

b) When the output voltage of the generator is 400 V, the air circuit breaker may be adopted as the generator circuit breaker.

c) The parameters of the circuit breaker shall be selected in accordance with the items given in Table 10.

Table 10 — Calculation formulae for selection of the circuit breaker

No.	Selection basis	Calculation formulae	Unit	Key
1	Operating voltage	$U_{max} \geq U_g$	V	U_{max} : Maximum allowable operating voltage of the circuit breaker; U_g : Maximum operating voltage of the circuit.
2	Operating current	$I_n \geq I_g$	A	I_n : Long-term allowable operating current of the circuit breaker; I_g : Continuous operating current of the circuit.
3	Breaking current	$I_{dn} \geq I_{dt}$	kA	I_{dn} : Rated breaking current of the circuit breaker; I_{dt} : Short circuit current of the circuit at t second (in general, the t value shall be the actual breaking time of the circuit breakers, i.e. the sum of the action time of the relaying protection and inherent breaking time of the circuit breaker).
4	Rated making current	$i_{Gn} \geq i_{ch}$	kA	i_{Gn} : Peak value of the rated closing current of the circuit breaker; i_{ch} : Peak value of the short circuit impact current of the circuit.

Table 10 *(continued)*

No.	Selection basis	Calculation formulae	Unit	Key
5	Verified on the basis of the thermal stability	$Q_t \geq Q_{dt}$ $Q_t = I_t^2 \cdot t$	kA²·s	Q_t : Allowable thermal effect of the circuit breaker; Q_{dt} : Thermal effect of the short circuit current of the circuit at t second; I_t : Thermal stability current of the circuit breaker; t: Action time of the thermal stability current.
6	Verified on the basis of the dynamic stability	$i_{gf} \geq i_{ch}$	kA	i_{gf} : Peak value of the limit current of the circuit breaker. i_{ch} : Peak value of the short circuit impact current of the circuit.

9.4.3 The parameters of the isolating switch shall be selected in accordance with the items given in Table 11.

Table 11 — Calculation formulae for selection of the isolating switch

No.	Selection basis	Calculation formulae	Unit	Key
1	Operating voltage	$U_{max} \geq U_g$	V	U_{max} : Maximum allowable operating voltage of the isolating switch; U_g : Maximum operating voltage of the circuit.
2	Operating current	$I_n \geq I_g$	A	I_n : Long-term allowable operating current of the isolating switch; I_g : Continuous operating current of the circuit.
3	Verified on the basis of the thermal stability	$Q_t \geq Q_{dt}$ $Q_t = I_t^2 \cdot t$	kA²·s	Q_t : Allowable thermal effect of the isolating switch; Q_{dt} : Thermal effect of the short circuit current of the circuit at t second; I_t : Thermal stability current of the isolating switch; t: Action time of the thermal stability current.
4	Verified on the basis of the dynamic stability	$i_{gf} \geq i_{ch}$	kA	i_{gf} : Peak value of the limit current of the isolating switch; i_{ch} : Peak value of the short circuit impact current of the circuit.

9.4.4 The selection and calculation of the current transformer shall comply with the requirements in Table 12.

Table 12 — Calculation formulae for the selection of the current transformer

No.	Selection basis	Calculation formulae	Unit	Key
1	Operating voltage	$U_{max} \geq U_g$	V	U_{max} : Maximum allowable operating voltage of the current transformer; U_g : Maximum operating voltage of the circuit.
2	Operating current	$I_{n1} \geq I_g$	A	I_{n1} : Rated current of the primary winding of the current transformer; I_g : Continuous operating current of the circuit.
3	Verified on the basis of the thermal stability	$K_t \geq \frac{I_t}{I_{n1}}$ which may also be written as: $K_t \geq \sqrt{\frac{Q_{dt}}{I_{n1}}} \times 10^3$		K_t : Thermal stability current of the current transformer; I_t : Thermal stability current of the current transformer (normally expressed by 1 second); Q_{dt} : Thermal effect caused by the short circuit current ($kA^2 \cdot s$).
4	Verified on the basis of the dynamic stability	$i_{gf} \geq i_{ch}$ or $K_d \geq \frac{i_{ch}}{\sqrt{2} I_{n1}} \times 10^3$	kA	i_{gf} : Peak value of the limit current of the current transformer; i_{ch} : Peak value of the short circuit impact current of the circuit. K_d : Multiple of the dynamic current.
5	The current transformer shall also be selected and verified in accordance with the different requirements for protection and measurement, and the secondary load, precision level and multiple of 10 %.			

9.4.5 The selection of the high-voltage load switch and the high-voltage fuse shall meet the following requirements.

a) The high-voltage load switch shall be selected on the basis of the items given in Table 13.

Table 13 — Calculation formulae for selection of the high-voltage load switch

No.	Selection basis	Calculation formulae	Unit	Key
1	Operating voltage	$U_n \geq U_g$	kV	U_n : Rated voltage of the load switch; U_g : Maximum operating voltage of the circuit.
2	Operating current	$I_n \geq I_g$	A	I_n : Rated current of the high-voltage load switch; I_g : Continuous operating current of the circuit.

Table 13 *(continued)*

No.	Selection basis	Calculation formulae	Unit	Key
3	Breaking current	$I_{dn} \geq I$	kA	I_{dn} : Maximum breaking current of the high-voltage load switch; I : Short-time maximum overload current of the circuit.
4	Verified on the basis of the thermal stability	$Q_t \geq Q_{dt}$	$kA^2 \cdot s$	Q_{dt} : Thermal effect caused by the short circuit current ($kA^2 \cdot s$); Q_t : Allowable thermal effect of the load switch.
5	Verified on the basis of the thermal stability	$i_{gf} \geq i_{ch}$	kA	i_{gf} : Peak value of the limit current of the load switch; i_{ch} : Peak value of the short circuit impact current of the circuit.

b) The high-voltage fuse shall be selected in accordance with the items given in Table 14.

Table 14 — Calculation formulae for selection of the high-voltage fuse

No.	Selection basis	Calculation formulae	Unit	Key
1	Operating voltage	$U_{max} \geq U_g$	kV	U_{max} : Maximum allowable operating voltage of the equipment U_g : Circuit operating voltage
2	Operating current	$I_n \geq I_{nj} \geq I_g$	A	I_n : Rated current of the fuse I_{nj} : Rated fusing current I_g : Continuous operating current of the circuit
3	Breaking capacity	$S_{dn} \geq S_d$ or $I_{dn} \geq I_d$		S_{dn} : Rated breaking capacity of the fuse (MVA) S_d : Short circuit capacity of zero second (MVA) I_{dn} : Rated breaking current of the fuse (kA) I_d : Secondary transient current of the short circuit (kA)
4	Protection characteristics a) For high-voltage fuse used to protect the power transformer, the rated current of melt may be selected by means of the following formula:	$I_{nj} = K_{st} I_n$		K_{st} coefficient: When the automatic starting of the motor is not considered, the value shall be 1,1 to 1,3; when the automatic starting is considered, the value shall be 1,5 to 2,0 I_n : Rated current on the high-voltage side of the transformer

Table 14 *(continued)*

No.	Selection basis	Calculation formulae	Unit	Key
4	Protection characteristics b) For the fuse used to protect the power capacitor, the rated current of melt may be selected by means of the following formula	$I_{nj} = K_r I_{nc}$		K_r coefficient: As for the drop-type high-voltage fuse, the value shall be 1,2 to 1,3; as for the current-limiting type high-voltage fuse, when there is one power capacitor, the value shall be set as 1,5 to 2,0; when there is a group of power capacitors, the value shall be set as 1,3 to 1,8 I_{nc}: Rated current of the power capacitor circuit

9.4.6 The selection and laying of the cable shall meet the following requirements.

a) The power cable should be flame-retardant cable. The selection of power cable section is generally determined by the continuous operating current, thermal stability or voltage drop of the circuit.

b) The power cable and the control cable should be laid separately. When they are laid on the same cable tray (or bridge), the control cable shall be laid below the power cable.

c) The depth of buried cable should not be less than 700 mm.

d) The holes on the upper and lower ends of the cable shaft and on the wall, cabinet and floor where the cable traverses shall be sealed with non-flammable material.

9.5 Overvoltage protection and earthing system

9.5.1 Direct lightning overvoltage protection devices (lightning rod, lightning conductor, etc.) shall be equipped for the outdoor switchgear installation and outdoor oil tanks.

9.5.2 Lightning rods may be installed on the frames of high-voltage switchgear installation of 110 kV and above, but they shall not be installed on the frames of high-voltage switchgear installation of 35 kV and below, or on the transformer portal frames.

9.5.3 The earthing device shall be designed with an artificial grounding network, and the following natural grounding conductors shall be used:

a) surface steel bars of reinforced concrete hydraulic structures that are in contact with water all year round;

b) embedded metal parts of penstocks, gates and trash racks;

c) metal conductor left underground or submerged in water.

9.5.4 The connection point between the natural grounding conductor and the artificial grounding network shall be no less than two.

9.5.5 In a small earthing short-circuit current system, the ground resistance shall not be greater than 4Ω. In a big earthing short-circuit current system, the ground resistance shall be in compliance with Formula (10):

$$R \leq 2\,000/I \tag{10}$$

where

R is the maximum earthing resistance in consideration of seasonal change, in Ω;

I is the maximum ground-entering current passing through the grounding device, in A.

9.5.6 An independent lightning rod (conductor) should be equipped with an independent grounding device, and its power-frequency ground resistance should not exceed 10 Ω. In areas with high soil resistivity, it may be connected to the main grounding network, and the underground length of the connecting wire shall not be less than 15 m.

9.6 Lighting system

9.6.1 The power supply for working lighting and emergency lighting of the power plant shall be set up separately. Working lighting shall be supplied by the plant service power system. Emergency lighting may be powered by a battery bank when all AC power is gone.

9.6.2 The premises and main passages where work needs to continue after the working lighting is interrupted shall be equipped with independent emergency lighting.

9.7 Layout of main electrical equipment inside and outside the power plant

9.7.1 The main transformer and switchyard should be close to the powerhouse. When the switchyard and the main transformer are arranged separately, the main transformer shall be installed near the generator switchgear installation room.

9.7.2 The switchgear installation with 6 kV to 35 kV may be arranged indoor with a complete switchgear, or outdoor. The switchgear installation with 66 kV or more preferably be arranged outdoor. However, in the polluted area or if terrain conditions are restricted, enclosed assembled switchgear may also be adopted.

9.7.3 The central control room shall be set up in accordance with the automatic control mode of the power plant.

9.8 Relaying protection and security automatic equipment

9.8.1 The selection and configuration of the relaying protection shall meet the requirements of the main electrical connection of the power plant, and in consideration of the operational flexibility of the grid and power plant.

9.8.2 The electrical equipment and transmission lines shall be equipped with main protection and backup protection devices.

9.8.3 The minimum sensitivity coefficient of relaying protection shall meet the provisions in Table 15.

Table 15 — Minimum sensitivity coefficient of the relaying protection

Category of protection	Type of protection	Component	Sensitivity coefficient	Remarks
Main protection	Longitudinal differential protection for generator and transformer	Starting current of the differential current element	1,5	—
	Current quick-break protection for generator, transformer and lines	Current element	1,5	Calculated as short circuit at the installation position of the protection

Table 15 *(continued)*

Category of protection	Type of protection	Component	Sensitivity coefficient	Remarks
	Complete current differential protection for bus	Starting current of the differential current element	1,5	—
	Incomplete current differential protection for bus	Differential current element	1,5	—
Backup protection	Remote backup protection	Current, voltage and impedance elements	1,2	Calculated as short circuit at the adjacent electrical equipment and the end of line (The short circuit current shall be more than 1,5 times the accurate operating current of the impedance element), while the relaying action may be taken into account.
		Zero-sequence or negative-sequence directional element	1,5	
	Near backup protection	Current, voltage and impedance elements	1,3	Calculated on the basis of short circuit at the end of line
		Negative-sequence or zero-sequence directional element	2	
Auxiliary protection	Current quick-break protection		1,2	Calculated on the basis of short circuit at the installation position of the protection under normal operating mode

9.8.4 The generator shall be equipped with corresponding protection against the following faults and abnormal operations:

a) internal phase to phase short circuit of the stator winding;

b) earthing of the stator winding;

c) external phase to phase short circuit of the generator;

d) overvoltage of the stator winding;

e) overload of the stator winding;

f) overload of the field winding;

g) one-point earthing of the field circuit;

h) abnormal reduction or loss of the excitation current;

i) disconnection from the system during phase-regulating operation;

j) other faults and abnormal operations.

9.8.5 The main transformer shall be equipped with corresponding protection against the following faults and abnormal operations:

a) phase to phase short circuit of the winding and its outlet leads;

b) over-current caused by external short circuit;

c) single-phase earthing fault on the side of the neutral point which is not effectively grounded;

d) inter turn short circuit;

e) overload;

f) drop of oil level;

g) high temperature of oil and winding, high tank pressure and cooling system failure.

9.8.6 Special bus bar protection shall be provided under the following circumstances:

a) for the 3 kV to 10 kV segmented busbar and double busbar in parallel operation:

   1) when it is necessary to quickly and selectively remove a section or a group of busbar fault, in order to ensure the safe operation of power plant and power grid and reliable power supply of important loads;

   2) when the line circuit breaker is not allowed to cut off the short circuit in front of the line reactor;

b) for the 35(33) kV to 110(132) kV bus of the power plant, when the fault on a busbar needs to be cut off quickly.

9.9 Excitation system

9.9.1 The excitation system shall be selected on the basis of the excitation mode and the operation mode of the generator.

9.9.2 The parameters of the excitation transformer, power unit and de-excitation device shall be calculated on the basis of the generator unit parameters.

9.10 Automatic monitoring system

9.10.1 The computer monitoring system shall be selected according to the installed capacity, unit capacity and voltage level of power plant, from comprehensive analysis on technical, economic and operational safety and reliability.

9.10.2 According to the characteristics of the power plant, the operating mode and the dispatching requirements of the power system, the control mode with fewer people on duty or unattended mode shall be selected.

9.10.3 The computer monitoring system shall meet the following requirements.

a) The command information of dispatching can be accepted at any time, which can meet the functions of the dispatching automation system for telemetry, remote signal, remote adjustment and remote control of the hydropower plant.

b) The unit start-up, grid connection and shutdown can be completed with one command.

c) The active power and reactive power of the unit can be automatically adjusted.

d) The automatic and economical operation of the entire plant can be realized.

9.11 Plant service power supply and dam area power supply

9.11.1 The plant service power supply shall meet the following requirements:

a) meet the needs of power load under various operating modes;

b) relatively independent power supply;

c) no less than two plant service power supplies are required. when one power supply fails, another power supply can operate automatically.

9.11.2 The plant service power supply may be obtained by the following methods:

a) connected by the generator voltage bus or the unit lead;

b) when a coupling transformer is equipped on the high-voltage side of the hydropower plant, the power supply is connected by the tertiary winding of the transformer;

c) the power supply is connected from the local power grid;

d) the diesel generator is used as the backup power supply.

9.11.3 Power for dam area shall be supplied by a special dam area transformer or a public plant service transformer. There shall be two independent power supplies for significant loads in the dam area. For particularly important flood discharge facilities, a third power supply or special diesel generator set of suitable capacity may be added.

9.11.4 Local power grid step-down transformer is preferentially used for the power supply in the hydropower plant living area.

9.12 DC operating power supply

9.12.1 The operating power supply of the power plant shall be the DC power supply device with storage battery and suitable battery chargers and shall work in the float charging mode.

9.12.2 The voltage of the DC operating power supply should be the standard voltage of DC 220 V or 110 V.

9.12.3 The capacity of the storage battery shall meet the needs for capacity when the entire plant is powered off owing to an accident and for the capacity of the maximum impact load. The accidental power-off time may be set preferably as 1 hour for the power plant.

9.13 Video monitoring system

The power plant should be equipped with the video monitoring system. The monitoring points shall be determined in light of the production, operation, fire-protection monitoring and the necessary safeguard.

9.14 Communication

9.14.1 The power plant shall be equipped with the in-plant communication facilities. The power dispatching communication and in-plant communication may share a program-controlled dispatching switchboard. As for the cascade hydropower plants, a dispatching switchboard may be set up in the cascade control centre, and a remote subscriber module may be set up on the power plant side to realize voice communication.

9.14.2 The power supply for the communication equipment shall be the special 24 V or 48 V communication power supply, and the capacity of the storage battery with suitable battery charger shall meet the power supply preferably for 8 hours.

10 Hydro mechanical structure

10.1 General provisions

10.1.1 The overall layout of hydro mechanical structure shall be mainly to determine the location of gates and hoists, orifice size, gate type, number and operation mode and other layout requirements related to operation.

10.1.2 The layout of the gates in the hydraulic structures shall keep the flow smooth and avoid the transverse flow and vortices forming upstream of the gate, and submerged discharge and backflow downstream of the gate. When a gate is set up at an inlet, water shall not be allowed to pass through the bottom and over the top of the gate simultaneously, so as to prevent turbulent state flow and cavitation erosion forming downstream of the gate slot.

10.1.3 The type of the gate shall be selected through technical and economic consideration in the light of the operation requirements of the gate, the working conditions of the gate and the type of the hoist. The characteristics of various types of the gates shall also be considered.

10.1.4 The size of the gate orifice shall meet the requirements of the flow rate, the total water pressure undertaken by the gate, the operating conditions and the requirements for the manufacture and installation of the gate and the hoist.

10.1.5 Ecological discharge equipment and its monitoring facilities should be set up.

10.2 Arrangement of hydro mechanical structure

10.2.1 Arrangement of hydro mechanical structure for surface spillways shall meet the following requirements.

a) The bulkhead gate should be installed upstream of the service gate of the spillway. When the duration of reservoir water level lower than the gate sill is sufficient for overhaul, it is not required to build bulkhead gates. The type of bulkhead gate may be plane sliding gate, or stoplog, floating stoplog or floating bulkhead gate based on the actual situation of the project.

b) The surface spillway service gate shall be selected based on factors such as the operating requirements of the project, the operating conditions of the gate, the type of hoist, and technical and economic indicators; the plane gate and radial gate may be adopted here.

c) The operating equipment of the spillway and service gates shall be provided with not only reliable common power supply but also standby power.

10.2.2 Arrangement of hydro mechanical structure for deep-type drainage sluices shall meet the following requirements.

a) Emergency gates shall be equipped upstream of the deep-type drainage sluice, which shall not only be able to close the orifice in the running water if an accident occurs upstream or downstream of the service gate, but also be used to retain water or as a bulkhead gate in normal operation.

b) When the deep-type drainage sluice is a non-pressure orifice, and there is a mobile hoist for the operation of the gate, it may be considered that one inlet emergency gate shared by several orifices. However, if the deep-type drainage sluice is a pressure orifice, and the service gate is set up at the outlet, then every orifice may be equipped with a separate emergency gate.

c) The type of the deep-orifice service gate shall be determined by the technical and economic consideration according to the factors such as the operating head, hydraulic layout and application conditions of the gate. Radial gate, plane gate, conical valve and other gates (valves) may be selected according to the specific situation.

d) The deep-orifice service gate shall be installed at the end of a pressure conduit, and the hoist chamber shall be located on the crest of the dam or in the dam.

e) The non-pressure free-flow section of a deep-type drainage sluice should be straight.

f) When the service gate is installed in the middle section of a deep drainage channel, the in-orifice pressure may be increased, and the pressure distribution condition at the inlet and near the gate slot can be improved by selecting an appropriate outlet contraction plate and pressure slope line for the sluice. In the course of opening/closing a gate, the alternative occurrence of pressure flow and non-pressure flow shall be avoided.

g) A reliable standby power source shall be prepared for the hoists used to manipulate flood discharge and other emergency gates.

10.2.3 Arrangement of hydro mechanical structure for water diversion shall meet the following requirements.

a) The trash rack shall be designed and installed based on the importance of the power plant and the nature, and expected quantity, of the trash. In the layout design, conditions such as water flow direction and favourable topographical location should be utilized so that the accumulation of trash in front of trash rack is avoided or reduced. The design should also seek to ensure that the incoming water flow is smooth, the resistance loss is minimized, the racks are easy to clean, and easy to install, maintain and replace.

b) The trash removal from trash racks may include manual mode, mechanical mode and racking-lifting mode.

c) Differential pressure measuring instruments and alarm devices should be installed at the intake of the hydropower plant to monitor the water level difference in front of and at the rear of the trash racks.

d) The bulkhead gates should be set up at the water inlet, and a plane sliding gate should be selected. If the utilization hours of the turbine generator unit in a power plant are relatively small, the stop time is relatively long, and the requirements for the maintenance of an emergency gate or a quick shutoff gate can be satisfied, the water intake bulkhead gate may be omitted.

e) For diversion-type power plants, the bulkhead gate or emergency gate shall be installed at the inlet of the diversion conduit. The quick shutoff gate or emergency gate should be set up at the inlet of the penstock at the location of the surge shaft within the long diversion conduit.

f) The closing time for a quick shutoff gate shall meet the requirements for runaway prevention of the turbine generator unit and for penstock protection. Its lowering speed when getting close to the sill shall not be more than 5 m/min.

g) The hoisting equipment of a quick shutoff gate shall have both a local operating system and a remote operating system and shall be equipped with an opening indicating device. A reliable power source shall be equipped.

h) The emergency (quick shutoff) gate and bulkhead gate at the water intake of a power plant should be opened in static water. A reliable pressure measuring facility shall be installed at the water intake of the power plant.

i) In general, a plane sliding gate shall be adopted as the tailwater bulkhead gate. A movable hoist should be installed when gate holes are shared.

10.3 Hoist selection for gates

In selection and arrangement of hoists, the advantages and disadvantages of various types of hoists shall be compared and the opening/closing mode of gates shall be analysed.

a) For the gate closed by dead weights or added weights and required to be fully opened within a short time, a fixed winch hoist or a hydraulic hoist should be adopted.

b) For the gate required to be fully opened in a short time or down force required, a hydraulic hoist should be selected.

c) For the plane gate which has many orifices and such orifices are not required to be opened evenly and partially at the same time, a mobile hoist should be selected.

d) For the small gate that down force required, a screw-type hoist should be selected.

10.4 Gate structure design

10.4.1 Gate design and calculation should include layout of the gate structure, calculation of the gate load, calculation of the components of the gate, calculation of the opening and closing forces of the gate and design of the vent holes.

10.4.2 Water pressure calculations should include static water pressure, dynamic water pressure, silt pressure, the force of floating material and other loads, including seismic load, wind load and frost load.

10.4.3 Layout of gate slot shall include type selection of the gate slot, determine the structure and related dimensions of the breast wall lintel.

10.4.4 Where there is insufficient ventilation behind a submerged gate, an air vent shall be installed at the top of the orifice closest to the downstream face of the gate. The open end of the vent should be separate from the hoist room and it should be above the checked flood level and with protective facilities.

10.4.5 The area of the rear vent hole behind a quick shutoff gate in a water diversion and a power generation conduit shall be selected as between 4 % and 7 % of the area of the power generation conduit; and the area of the vent hole of an emergency gate may be reduced appropriately based on the actual situation.

10.4.6 The area of the vent hole behind a bulkhead gate shall not be less than the area of the charging conduit.

10.5 Anti-corrosion of hydro mechanical structures

10.5.1 Anti-corrosion measures and surface pre-treatment shall meet the following requirements.

a) During the design of hydro mechanical equipment, the anti-corrosion measures shall be selected after technical and economic consideration have been carried out that consider factors such as operating environment, operating conditions, maintenance and management conditions of the structures.

b) Three measures may be adopted for the anti-corrosion of hydro mechanical structures, they are anti-corrosion coating, sprayed metal anti-corrosion coating and cathodic anti-corrosion protection.

c) The surface of hydro mechanical structures shall be pre-treated before coating.

d) The design document shall specify the surface pre-treatment cleanliness and surface roughness level and quality assessment standards.

10.5.2 Coating protection shall meet the following requirements.

a) The anti-corrosion coating should be composed of primer, intermediate paint and finishing coat. The primer shall have good adhesive force and rust resistance, the intermediate paint shall have shielding performance and good combination with the primer and finishing coat, and the finishing coat shall have weather and water resistance.

b) The coating system shall be selected based on the surrounding environment.

10.5.3 Sprayed metal anti-corrosion coating shall meet the following requirements.

a) The sprayed metal anti-corrosion coating system may include sprayed-metal coating and sealing coating layer. The thermal sprayed metal and coating protection system shall be applied with intermediate paint and finishing coat after the coating is sealed.

b) The metal wires used for thermal spraying shall be clean and free of rust, oil or fold marks, and the wire diameter should be less than 3,0 mm.

c) In the sprayed metal coating protection system, the thickness of the metal coating may be determined based on the environmental factors.

d) The sealing coating shall be compatible with a sprayed metal coating, with relatively low viscosity and certain corrosion resistance.

10.5.4 Cathodic anti-corrosion protection shall meet the following requirements.

a) Before design of cathodic anti-corrosion protection, the following data shall be collected and, if necessary, an on-site survey shall be carried out:

   1) data about the design and construction of the hydro mechanical structures;

   2) types, conditions and service life of the coating on the surface of the hydro mechanical structures;

   3) electrical continuity of the hydro mechanical structures, and electrical insulation from the other hydro mechanical structures under the water;

   4) chemical composition, PH value, resistance rate, contamination degree of the medium and variations of temperature, flow velocity and water level.

b) The cathodic anti-corrosion protection shall be used together with coating protection.

c) The hydro mechanical structures applied with cathodic protection shall be insulated from the other hydro mechanical structures in the water.

d) The actual service life of the cathodic protection system shall be determined based on the design service life or the maintenance period of the metal structure.

11 Guidelines for construction planning

11.1 Construction diversion

11.1.1 Construction diversion standard shall be selected according to the following principles.

a) The flood control standards of construction diversion structures shall be expressed as the recurrence period of the flood, which may be determined according to Table 16.

Table 16 — Flood control standards for diversion structures

Diversion structure type	Flood recurrence period (year)
Earth- rock structure	5~10
Concrete, masonry structure	3~5

b) The closure period shall be selected based on the comprehensive analysis of hydrological characteristics, climatic conditions, cofferdam construction conditions, construction progress and navigation requirements. The closure period should be arranged in the dry period and severe cold area should avoid ice and freezing period. The standard diversion discharge may be the monthly, or the 10 day average flow rate, for a recurrence period of 3 to 10 years during the diversion period.

c) When the dam elevation exceeds the cofferdam crest elevation, the temporary flood control standard for flood control of dam body during flood season, shall be determined on the basis of the dam type as indicated in Table 17. The standard may also be raised or lowered according to the accident impact on downstream areas after special demonstration.

Table 17 — Temporary flood control standards for flood control of dam body in construction period

Dam type	Flood recurrence period (year)	
	Flood retention by the dam in flood season, during the construction period	Flood control by the dam after the blockage of the diversion structure
Earth-rockfill dam	10~20	20~30
Concrete dam, masonry dam	5~10	10~20

d) The blocking time of the diversion structure shall be determined according to the overall construction progress based on the premise of meeting the requirements of flood retention and impoundment for the reservoir. The design flow rate during the blockage may be the monthly or 10 day average flow rate for the recurrence period of 5 to 10 years, or it may be determined by the analysis of the actually measured hydrologic statistical data. The design standard of diversion during the construction period shall be selected according to the importance of the project, accident consequences and other factors within 5 to 30 years recurrence period.

e) The impoundment standard of a reservoir during the construction period shall be determined on the basis of the requirements of power generation, irrigation, navigation and water supply and the safety of the dam, and the guarantee rate should be 75 % to 90 %.

f) During the blockage of a diversion structure and the impoundment of a reservoir, the downstream water supply and ecological flow shall be guaranteed.

11.1.2 Construction diversion may include phased cofferdam diversion mode and one-time riverbed cut-off cofferdam diversion mode, and the supporting works may include open channel diversion, tunnel diversion, conduit diversion, bottom outlet diversion, dam-gap diversion and combined diversions of different flood releasing structures. The selection of the construction diversion mode shall comply with the following principles.

a) The diversion mode shall be adaptive to the hydrological characteristics of the river and the topographical and geological conditions.

b) The construction period shall be short, and the construction shall be safe, flexible and convenient.

c) The permanent structure shall be effectively utilized to reduce the quantity and cost of the diversion works.

d) Construction diversion mode shall meet navigation, ice clearing, ecological flow, water supply and other requirements.

e) Diversion works from initial to later stages (i.e. river closure, cofferdam water retention, dam body flood control, blockage of diversion works and water supply) shall be reasonably integrated during the construction period.

11.2 Selection, planning and exploitation of the borrow area

11.2.1 The sources of natural building materials shall include excavated materials of buildings, soil, natural sand and gravels and materials exploited from borrow areas. The material sources shall be selected according to the construction requirements for the building materials' quantities, quality and supply intensity. After a comprehensive analysis of material source distribution, reserves, quality, exploitation and transportation conditions, and working out an excavation-fill balancing plan, both on the basis of geological explorations and experiments, the selection shall be finalized through technical and economic consideration under the principle of high quality and cost effectiveness.

11.2.2 The borrow areas for an earth-rock fill dam shall be selected in compliance with the following principles.

a) The physical-mechanical characteristics of dam materials shall conform to the quality standard of dam materials.

b) The reserves are relatively concentrated, the top soil layer of the borrow area is thin while the material layer is thick, and the total reserves can meet the needs of the dam filling.

c) The borrow areas shall be used according to different parts of the dam body. Some borrow areas nearby shall be reserved for flood retention of dam.

d) The borrow areas shall be easily exploited, the working area shall be broad, the transportation distance shall be short, and there is disposal site nearby.

e) No or less occupation of farmland and forests.

f) No or less adverse impact on ecology of the area.

11.2.3 The selection of borrow areas for concrete aggregates shall be in compliance with the following principles.

a) When there are abundant natural sand and gravels near the project and their quality meets the standards, they shall be selected as the main material source.

b) When the reserve and quality of natural sand and gravels from the borrow areas near the main project works cannot meet the requirements, artificial aggregate should be excavated and processed nearby. The priority should be given to the excavated materials if they are of large quantity and good quality and can meet the requirements of construction progress.

c) No or less occupation of farmland and forests.

d) No or less adverse impact on ecology of the area.

11.3 Construction of the main works

11.3.1 The construction method of the main works shall economically and reasonably realize the overall design scheme of the project and shall ensure the project quality and construction safety. The complete and feasible construction method shall be determined, the rationality and feasibility of the overall construction progress shall be demonstrated, any alteration suggestions shall be raised for the layout of the hydraulic structures and building types, and the required data shall be provided for the compilation of the project estimate.

