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Technical guidelines for the development of small hydropower plants —

Part 3: Design principles and requirements

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Foreword

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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).

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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):

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

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