Technical Guidelines for the Development of Small Hydropower Plants

DESIGN

Part 6-3: Hydro Mechanical Works

SHP/TG 002-6-3: 2019
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Further recommendations and suggestions for application for the update would be highly welcome.
# Table of Contents

- Foreword VI
- Introduction VII
- 1 Scope 1
- 2 Normative references 1
- 3 Terms and definitions 1
- 4 Contents and requirements of design 1
  - 4.1 General requirements 1
  - 4.2 Collection of data 1
- 5 Selection and layout of equipment 2
  - 5.1 General requirements 2
  - 5.2 Arrangement of gates 2
  - 5.3 Type of gate and size of orifice 3
  - 5.4 Hoist 3
  - 5.5 Manufacture, transportation and other considerations 4
  - 5.6 Arrangement of hydro mechanical equipment for surface spillways 5
  - 5.7 Arrangement of hydro mechanical equipment for deep-type drainage sluices 6
  - 5.8 Arrangement of hydro mechanical equipment for water diversion and power generation systems 7
- 6 Hydraulic design and calculation 9
  - 6.1 Calculation of load on a gate 9
  - 6.2 Calculation of gate hoisting force 14
  - 6.3 Calculation of area of the vent hole 17
  - 6.4 Type selection and calculations for the gate slot of a plane gate 18
- 7 Anti-corrosion of hydro mechanical structures 20
  - 7.1 General requirements 20
  - 7.2 Coating protection 20
  - 7.3 Sprayed-metal anti-corrosion coating 21
  - 7.4 Sacrificial anode cathodic anti-corrosion protection 21
- 8 Workload of hydro mechanical structures 21
- Appendix A (Informative) Frictional coefficient 22
- Appendix B (Informative) Semi-theoretical and semi-empirical formula coefficient 23
The United Nations Industrial Development Organization (UNIDO) is a specialized agency under the United Nations system to promote globally inclusive and sustainable industrial development (ISID). The relevance of ISID as an integrated approach to all three pillars of sustainable development is recognized by the 2030 Agenda for Sustainable Development and the related Sustainable Development Goals (SDGs), which will frame United Nations and country efforts towards sustainable development in the next fifteen years. UNIDO’s mandate for ISID covers the need to support the creation of sustainable energy systems as energy is essential to economic and social development and to improving quality of life. International concern and debate over energy have grown increasingly over the past two decades, with the issues of poverty alleviation, environmental risks and climate change now taking centre stage.

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

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

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

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

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

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

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

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

DESIGN

Part 6-3: Hydro Mechanical Works
1 Scope
This part of the Design Guidelines sets out the contents and requirements for design of hydro mechanical works in an SHP station, and gives the specific requirements for the selection and arrangement of hydro mechanical equipment, hydraulic design calculations and anti-corrosion measures.

2 Normative references
The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.
SHP/TG 001, Technical guidelines for the development of small hydropower plants —Terms and definitions.

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

4 Contents and requirements of design

4.1 General requirements
4.1.1 Hydro mechanical works include trash racks, trash rakes, gates, hoisting equipment and hoist bridges. During the design of the overall layout, type selection, manufacture and installation of hydro mechanical equipment, close coordination with other disciplines and overall analysis shall be carried out, in order to achieve an optimal design.

4.1.2 Before preparation of the design documents for hydro mechanical works, the project equipment, the operating conditions, the requirements for control of water level, the impact of water discharging or leakage, the overall layout of the project and the construction schedule of the project shall be understood.

4.2 Collection of data
4.2.1 The basic data should include the requirements or provisions of relevant laws, regulations or norms and environmental protection that affects the operation of the project.

4.2.2 All gates should be designed with the following information, according to the specific situation:

a) Engineering tasks and layout of hydraulic structures;

b) Gate opening size and operating conditions;

c) Hydrological data, sediment loading, water quality data, ice conditions, floating matter and meteorological conditions;

d) The conditions for the material, manufacture, transport and installation of the gate;

e) Earthquake and other special requirements.
5 Selection and layout of equipment

5.1 General requirements

5.1.1 The overall layout of hydro mechanical structures shall include the installation position of gates and hoists, the dimensions of orifices, the type, number and operation mode of the gates and other layout requirements relevant to operation.

5.1.2 The layout and type of hydro mechanical structures shall be determined through technical and economic comparison in the light of the overall planning of the project and the overall layout of hydraulic structures. A design scheme that is of reliable quality, is safe and applicable, and is technically advanced and reasonably economic shall be selected.

5.2 Arrangement of gates

5.2.1 The arrangement of the gates in hydraulic structures should ensure smooth flow through the gates, and should avoid transversal flow occurring and vortices forming on the upstream side of the gate. The positioning should also prevent the occurrence of strong outflow and confluence on the downstream of the gate. When a gate is set up at an inlet, water should not be allowed to pass both through the bottom and over the top of the gate simultaneously; this could result in turbulent state flow and cavities forming downstream of the gate slot.

5.2.2 For important deep-bottom-orifice gates or hydraulically operated gates, the arrangement and shape of the waterway shall be carefully selected, so as to ensure that the gate and the gate slot will have favourable hydraulic conditions.

5.2.3 When a hydraulic structure is used for flood discharging or power generation and the orifices are arranged at different elevations, they should be staggered and should not overlap.

5.2.4 Gates used for water diversion and power generation systems shall be selected in accordance with the protection requirements for turbine generator units, the arrangement characteristics of water diversion and power generation systems, and with overall consideration of the arrangement, type and operation mode of the gate. In general, on a heavy sediment/silt-carrying river, the sand-discharge bottom holes or sand-discharge corridors shall be set up adjacent to the water intake for a power station, in order to reduce sedimentation in front of the water intake and hence to alleviate wear on the turbines and blockage of the trash racks.

5.2.5 The minimum net distance between two gates, or between a gate and a drain gate, should meet the requirements of both the concrete strength and impermeability of the gate groove, the layout and operation of the hoist, the installation and maintenance of the gate and hydraulic conditions, and should not be less than 1.50 m.

5.2.6 The top of an open-top gate should be between 0.3 m and 0.5 m above the highest anticipated water level.

5.2.7 The hoist for the working gate of the discharge and sluice system with flood control function must be equipped with a standby power supply.

5.2.8 Where there is insufficient ventilation behind a submerged gate of a permanent structure, an air vent must 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 should have protective facilities.

5.2.9 For the water pressure balancing facilities of a gate, it is recommended that one of the following water
filling options is used: a water filling valve installed on the door body, internode water filling, small opening water filling or other effective facilities. The operation of the water pressure balancing facilities should be linked with the opening and closing of the gate, and a small opening travel switch should be installed on the hoist. The water pressure balancing facilities for the tailgate of the unit should be filled with water from the downstream end using the unit drainage system.

5.3 Type of gate and size of orifice

5.3.1 The type of gate to be used shall be selected through technical and economic comparison in the light of the requirements of the project for the operation of the gate, the working conditions of the gate and the type of hoist. The different characteristics of various types of gates should also be considered.

5.3.2 The size of a 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 hoist.

5.3.3 When the water head is high, it is advisable to adopt an orifice with a relatively small width-to-height ratio; when the water head is low, it is advisable to adopt an orifice with a relatively large width-to-height ratio.

5.4 Hoist

5.4.1 In the overall arrangement, the advantages and disadvantages of various types of hoists shall be compared and the opening/closing mode of gates should be analyzed. Besides the hoist’s design function, the possibility and/or necessity of other usages should also be considered.

5.4.2 The type of hoist shall be selected in accordance with the following requirements, in the light of factors such as the type and dimensions of the gate, the maximum head and the operating conditions of the orifice:

a) For gates which are closed by deadweights or added weights and are required to be fully open within a short time period, either a fixed winch hoist or a hydraulic hoist should be adopted.

b) For gates which are required to be fully open in a short time period or have downward-pressing requirements, a hydraulic hoist should be selected.

c) For plane gates which have many orifices and such orifices are not required to be evenly and partially opened at the same time, a movable hoist should be selected. The number of hoists shall be determined in light of the requirements for the opening times of the gate, and an appropriate number of backup hoists shall be considered. When a gantry gate hoist is set up, the maintenance requirements for the hydro mechanical equipment on top of a dam, as well as the requirements for the dam itself shall be considered.

d) For small gates which have downward-pressing requirements, a screw-type hoist should be selected.

e) The opening/closing capacity of the hoist selected shall not be less than the calculated hoisting force plus a margin of safety.

5.4.3 The lift of a hoist may be decided in light of operating conditions, and shall meet the following requirements:

a) The overflow gate should be lifted to between 1m and 2m above the water surface.

b) The quick shutoff gate shall be lifted to between 0.5m and 1.0m above the orifice.

c) The gate shall be lifted to between 0.5m and 1.0m above the maintenance platform for inspection, repair or replacement.
5.4.4 If a movable hoist is used to operate a multi-orifice gate, or the boom has to be erected and dismantled frequently during the operation of the gate, an automatic pick-up beam should be adopted, for which the mechanical or hydraulic type may be selected in light of the operating conditions. When the gate is equipped with an automatic pick-up beam, the following requirements shall be satisfied:

a) The upstream waterstop shall be set up for the gate. If the gate is equipped with a downstream waterstop, attention shall be paid to the reliability of the underwater operation of an automatic pick-up beam.

b) During the underwater operation of an automatic pick-up beam, attention shall be paid to the impact caused by disturbance of water flow on its stability.

c) Attention shall be paid to the construction and installation precision of the gate slot, so as to ensure that the automatic pick-up beam can be used in multi-orifice slots.

d) The automatic pick-up beam shall be equipped with a guide, positioning and safety devices, as well as gas/water drainage holes.

e) The automatic pick-up beam shall go through static balance testing, to ensure smooth operation. When being put into the slot, the beam shall not be tilted or jammed.

f) When the operating temperature may be lower than 0°C, measures for preventing the components picked from getting frozen during operation or under water shall also be provided.

5.5 Manufacture, transportation and other considerations

5.5.1 In the overall arrangements for the gate, the manufacturing material of the gate and the spare parts required for formation of the gate shall be considered. The types and quantity of such spare parts shall be minimized, and, if possible, standard and conventional products shall be adopted, to ensure sufficient supply during the construction period, and during repair and maintenance.

5.5.2 If possible, the construction technology applied during the manufacture of the gate and its assembly, and the welding technology applied during the installation of the gate shall be small, in order to avoid the employment of specialized devices and equipment, and to minimize any on-site workload and potential working at height.

5.5.3 A plane gate should be tested for static balance. When the tilt value of the gate exceeds the design requirements, it should be weighted.

5.5.4 The transportation conditions for equipment shall be studied, and it is recommended that selection includes gate types and materials that are easy to handle, and have fewer, smaller and lighter pieces, with enough rigidity to prevent distortion during transportation and erection. Sizes and weights that exceed transportation limits are to be avoided.

5.5.5 During the construction or operation period, no matter what the scale of the project is, any sites for storage, assembly, maintenance and repair of gates and their components shall be subject to overall design and arrangements, favourable for operation, maintenance and safety.

5.5.6 The necessity of setting up a hoist room shall be determined in light of the local climatic conditions such as sunlight, atmospheric conditions, temperature, rainfall, hail, wind and sand storms. The type of hoist, and its operation and maintenance requirements, shall also be taken into account. The hoist room and assembly site shall be designed with due consideration to the safety and convenience of operating personnel. Structural measures shall be set at the edge of the gate well to prevent sundries from falling into the well, so as not to affect the operation of the gate.
5.5.7 The location for the installation of backup power shall be carefully considered.

5.5.8 In cold regions where freezing may occur, the appropriate anti-freezing measures shall be taken for the gate structure and the gate slot, so that operation of the gates may be carried out smoothly during very cold weather conditions.

5.6 Arrangement of hydro mechanical equipment for surface spillways

5.6.1 The bulkhead gate and hoisting equipment shall be designed in accordance with the following requirements:

a) The bulkhead gate should be installed upstream of the service gate of the spillway. The following types of bulkhead gates are acceptable and selection should be based on site specific conditions, plane sliding gates, stoplogs or floating-type stoplogs.

b) If there is a sufficient continuous time period every year, when the water level in the reservoir is lower than the bottom sill of gate and the requirements for maintenance of the gate can be satisfied, the bulkhead gate may be omitted. However, if it is inappropriate to undertake maintenance in such periods due to reasons such as cold weather, a bulkhead gate shall be installed.

c) In general, no emergency gate shall be installed in front of the gate for emersed discharge orifice. However, for some projects, or for the service gate of a spillway where there is a wood-passing requirement, an emergency gate may be installed to ensure the safety of discharging flood flows and the prevention of blockage by floating wood.

d) When a plane service gate is adopted for spillways and a movable hoist is set up for operation, one or two backup service gates may be provided to allow maintenance of the service gate and its gate slot.

e) When a multi-orifice service gate in a water discharging system is operated by a movable hoist, the bulkhead gate may be used by multiple orifices, and the specific number of gates required shall be determined based on factors such as the number of orifices, the importance of the project and the applicable conditions and maintenance requirements of the service gate.

5.6.2 The type and elevation of surface service gates shall be determined by considering the following factors:

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

b) The position of the bottom edge of the gate on a weir crest should be slightly on the downstream side of the weir crest to reduce water overflow and avoid negative pressure on the dam surface. If there is bulkhead gate upstream of the service gate, the position of the service gate shall also meet the requirements for the arrangement of the hoist, as well as the requirements for the installation, operation, maintenance and overhaul of the gate; but its position should not be too low.

5.6.3 For the operating equipment for the spillway and service gate in the water gate system, a backup power supply shall be provided in addition to a reliable power source. A diesel generator unit is usually adopted as the backup power source. For hoisting equipment with a relatively small hoisting force, a manually operated device may be used in the event of a power failure, but the opening time of the gate shall meet the requirements for flood control operation.
5.7 Arrangement of hydro mechanical equipment for deep-type drainage sluices

5.7.1 The emergency gate, bulkhead gate and hoisting equipment shall be designed in accordance with the following requirements:

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

b) The position of a deep-orifice emergency gate, and the shape of the gate slot, shall be favourable for improving the hydrodynamic conditions of the waterway or inlet section, and shall normally be selected by reference to the experience of similar completed projects or through hydraulic model testing.

c) When the deep-type drainage sluice is a non-pressure orifice, and there is a movable hoist for the operation of the gate, the number of emergency gates at the inlet may be determined under the condition that several orifices share a gate. However, if the deep-type drainage sluice is a pressure orifice, and the service gate is set up at the outlet, then, in order to avoid long-term pressure on the sluice, every orifice may be equipped with a separate gate.

d) If the water level downstream of a deep-type drainage sluice often submerges the bottom sill in order to maintain the waterway, the tunnel and the embedded parts of gate slot, a downstream bulkhead gate may be set up if necessary.

e) A sand-discharging orifice shall be located as close as possible to the water inlet for power generation or irrigation, or to the head of ship gate, wherever sand needs to be discharged. Usually the inlet section of sand-discharging orifice shall be equipped with an inlet gate. Depending on the specific conditions of a sand-discharging gate, a high-pressure water gun may be set up to wash away sand and open the gate, if deemed necessary.

5.7.2 The type of deep-orifice service gate may be determined in accordance with the following requirements:

a) Radial gate: A radial gate may be preferentially selected as the deep-orifice drainage control equipment. If the size of the gate orifice is relatively large and the operational head of water is more than 50 m, or if it is considered to improve the hydrodynamic conditions of a deep-orifice service gate and the gate is required to be partially open, a radial gate should be selected.

b) Plane gate: In order to improve the arrangements for the outlet of an in-dam drainage waterway, or if a deep-orifice gate will not be partially opened and if the gate slot is properly designed, a plane gate may be adopted.

c) Conical valve: When it is possible to avoid the unfavourable impact of free jets on building and equipment located downstream of the power station, a conical valve may be adopted as deep-orifice service gate.

5.7.3 The deep-orifice service gate and hoisting equipment shall be designed in accordance with the following requirements:

a) The service gate shall be installed at the end of a pressure conduit, and the non-pressure free-flow section shall be connected behind the gate. The pressure section in front of the gate shall maintain a certain contraction rate, and the inlet-to-outlet area ratio shall be 1.5 to 1.7.

b) The non-pressure free-flow section of a deep-type drainage sluice should be straight. If there are curves in the discharging conduit, the service gate should be located within the straight section downstream of the last curve where the water flows smoothly.
c) 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. When the service gate and hoist are set up at the outlet of a pressure orifice, a radial gate may be adopted, but it is critical that the bearing mountings transferring the thrust of an arc gate, shall be properly located. If a plane gate is selected for the outlet, in order to improve the hydraulic conditions, a super cavitation jet gate slot may be adopted.

5.8 Arrangement of hydro mechanical equipment for water diversion and power generation systems

5.8.1 The trash rack, trash remover and hoisting equipment at the intake works shall be designed in accordance with the following requirements:

a) The trash rack shall be designed and installed based on the importance of the power station 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. The arrangement of the trash racks shall meet the requirements for the type of intake of the hydropower station.

b) The design load of the trash rack should be decided according to the nature, quantity and cleaning measures required for any sewage in the river. A water level difference between 2m to 4m should be adopted for trash racks for water diversion and power generation systems. For rivers with more pollutants and poor decontamination conditions, the design head should be raised appropriately.

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

5.8.2 The bulkhead gate and hoisting equipment at the water intake shall be designed in accordance with the following requirements:

a) In order to meet the requirements for maintenance of the turbine generator unit, the emergency gate and the quick shutoff gate, gate slot, and bulkhead gates should be set up at the water inlet. As for the type of bulkhead gate, a plane sliding gate may be selected.

b) If the utilization hours of the turbine generator unit in a power station are relatively small, the stop time is relatively long, the requirements for the maintenance of an emergency gate or a quick shutoff gate can be satisfied, and the appropriate safety measures are taken for embedded parts, such as gate slots to ensure construction quality, the water intake bulkhead gate may be omitted.

c) When the water intake bulkhead gate of a power station with several turbine generator units is operated by a movable hoist/gantry crane, several orifices may share one gate. The number of gates shall be determined based on factors such as the number of orifices, the importance of the project, and the application and maintenance conditions of emergency gates or quick shutoff gates. In general, one intake bulkhead gate may be set up for three to six turbine generator units; if there are more than six turbine generator units, one additional hoist may be set up for every four to six additional turbine generator units.

d) In order to simplify the inlet arrangement and shorten the length of the inlet conduit, the bulkhead gate
and trash rack may share the same slot. However, the arrangement of the gate slot and its embedded parts shall meet the opening/closing requirements of the gate and trash rack, and the structural strength shall also be designed in accordance with the requirements for the bulkhead gate.

5.8.3 The emergency gate and hoisting equipment at the intake shall be designed according to the following requirements:

a) When units or penstocks require accident protection of the gate, quick shutoff gates and bulkhead gates shall be installed at the intake of the power station at the dam toe. For a diversion power station, the quick shutoff gate is to be installed at the head end of the underground buried penstock, without a water inlet valve in front of the open penstock and the turbine; and the emergency gate should be installed at the entrance to the long diversion channel. For riverbed hydropower stations, when the unit has a reliable anti-runaway device, its intake should be equipped with an emergency gate and a bulkhead gate. After demonstration, the emergency gate has maintenance conditions, and it is not necessary to install the bulkhead gate. For a tubular turbine power station, a trash barrier and a bulkhead gate (or emergency gate) should be installed at the intake, and an emergency gate (or bulkhead gate) should be installed at the tail water outlet.

b) The emergency gate shall be installed based on the emergency protection requirements of the turbine generator units or penstocks. If the gate operating mechanism fails owing to of the malfunction of the turbine generator units or any accident occurs to the penstocks; the emergency gate shall be able to close the gate and cut-off the water flow quickly, to prevent any further damage resulting from the accident. If the diversion conduit or the turbine generator unit is under maintenance, the emergency gate may be used to retain water and used as a bulkhead gate.

c) For diversion-type power stations, 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 water inlet of the penstock at the location of the surge shaft within the long diversion conduit.

d) If the quick shutoff gate or emergency gate of a hydropower station is located within the surge shaft and often stays in the gate slot, the unfavourable impact of a surge event in the surge shaft on stopping or lowering of gate shall be considered.

e) 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 5m/min.

f) 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 a reliable power source.

g) In general, the emergency (quick shutoff) gate and bulkhead gate at the water intake of a power station are opened in static water. In order to monitor the pressure equalizing situation before opening the gate, a reliable pressure measuring facility shall be installed at the water intake of the power station.

5.8.4 The tailwater gate and hoisting equipment shall be designed in accordance with the following requirements:

a) The gate in the draft tube of the turbine generator unit is used to block the downstream tailwater to allow for the installation and maintenance of components such as the draft tube and turbine. Usually the gate is opened/closed in static water. For a tubular turbine power station with bulkhead gates at the intake, the emergency gate should be installed at tailwater outlet.
b) In general, a plane sliding gate shall be adopted as the tailwater bulkhead gate. Two tailwater bulkhead gates may be installed for three to six turbine generator units; if there are more than six turbine generator units, one additional hoist may be set up for every four to six additional turbine generator units. A movable hoist should be installed when gate holes are shared.

c) When a tailwater gate works under the design water head, it will be under pressure on the downstream tailwater face. Therefore, in order to fill sufficient water to equalize the pressure on the tailwater gate, water from tailwater shall usually be taken into the draft tube.

### 6 Hydraulic design and calculation

#### 6.1 Calculation of load on a gate

6.1.1 The static water pressure applied to a gate may be calculated by the means of formulas in Table 1.

#### Table 1 - Calculation of static water pressure

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Diagram of water pressure</th>
<th>Calculation formula</th>
</tr>
</thead>
</table>
| 1 | ![Diagram 1](image1.png) | Total water pressure: $P = \frac{1}{2} \gamma H_s^2 B_{zs}$
Position of acting point of force $P$: $H_c = \frac{2}{3} H_s$ |
| 2 | ![Diagram 2](image2.png) | Total water pressure: $P = \frac{1}{2} \gamma (H_s^2 - H_s^2) B_{zs}$
Position of acting point of force $P$: $H_c = \frac{1}{3} (2H_s - \frac{H_s^2}{H_s + H_c})$ |
| 3 | ![Diagram 3](image3.png) | Total water pressure: $P = \frac{1}{2} \gamma (2H_s - h) h B_{zs}$
Position of acting point of force $P$: $H_c = H_s - \frac{h \cdot 3H_s - 2h}{2H_s - h}$ |
Total water pressure:

\[ P = \gamma (H_s - H_c) h B_{ma} \]

Position of acting point of force \( P \):

\[ H_c = H_s - \frac{1}{2} h \]

Total water pressure:

\[ P = \frac{1}{2} \gamma ((2H_s - h)h - H_c^2) B_{ma} \]

Position of acting point of force \( P \):

\[ H_c = \frac{3H_sH_c^2 - H_c^3 - 6H_c^2h + 6H_c h^2 - 2h^3}{3H_c^2 - 6H_ch + 3h^3} \]

Total water pressure:

\[ P = \left( P_s - P_x \right)^2 + \left( V_s - V_x \right)^2 \]

\[ \phi_1 < \phi_2 \]

\[ P_s = \frac{1}{2} \gamma H_c^2 B \]

\[ V_s = \frac{1}{2} \gamma R^2 \left[ \frac{\pi \phi_2}{180} - 2 \sin \phi_1 \cos \phi_2 - \frac{1}{2} \left( \sin 2\phi_1 - \sin 2\phi_2 \right) \right] B \]

\[ P_x = \frac{1}{2} \gamma H_s^2 B \]

\[ V_x = \frac{1}{2} \gamma R^2 \left[ \frac{\pi \phi_s}{180} + 2 \sin \phi_1 \cos \phi_s - \frac{1}{2} \left( \sin 2\phi_1 + \sin 2\phi_s \right) \right] B \]

Total water pressure:

\[ P = \sqrt{(P_s - P_x)^2 + (V_s - V_x)^2} \]
6.1.2 The dynamic water pressure applied on a gate may be calculated in accordance with the following provisions:

a) For a service gate that is often operated in dynamic water conditions under a high water head or is often operated partially open, the different dynamic loads undertaken by different components of the gate shall be considered in the design, while the static load on the different components of the gate may be multiplied by different dynamic coefficients in accordance with the type and flow conditions of the gate. The value of the dynamic coefficient should be between 1.0 and 1.2. As for the main beam and supporting arm of an emerged radial gate, the value of the dynamic coefficient should be between 1.1 and 1.2. For important service gates in projects where the flow conditions are complicated, the dynamic coefficient shall be subject to a special study. The dynamic coefficient shall not be considered in the calculation of the rigidity of gate.
b) When the type of bottom edge indicated in Figure 1 is adopted, the uplift force may be calculated by using Formula (1):

\[ P_t = \gamma \beta_t H_s D_1 B_{zs} \]  
(1)

where

- \( P_t \) is the uplift force, in kN;
- \( H_s, D_1 \) see Figure 1, in m;
- \( B_{zs} \) is the interval of waterstops on both sides, in m;
- \( \gamma \) is the unit weight of water, in kN/m³;
- \( \beta_t \) is the uplift force coefficient. In the calculation of the gate closing force, it shall be considered that the gate is fully closed, and \( \beta_t = 1.0 \); in the calculation of the holding force, it may be considered for different opening positions \( s \) of the gate, and \( \beta_t \) may be determined by reference to Table and shall be verified through hydraulic model testing for special circumstances; the values of \( \beta_t \) given in Table 2 are applicable to the free-flow state behind the gate, and for sluiceway gates, \( 0 < a < 0.5 \) \( H \) (where \( H \) is the orifice height of diversion channel); for quick shutoff gates for a power station, \( 0 < a < a_k \) (where \( a_k \) is the critical opening for the transition from free to pressurized flow behind the gate when the quick shutoff gate of the power station is closed; this may be calculated based on experience of similar completed projects or by reference to the relevant testing and study reports; it may be determined through hydraulic model testing if necessary. Under normal circumstances, it may be temporarily estimated as \( a_k = 0.5H \)).
Table 2 - Uplift force coefficient $\beta_t$

<table>
<thead>
<tr>
<th>$\alpha (^\circ)$</th>
<th>$a/D_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>60°</td>
<td>0.8</td>
</tr>
<tr>
<td>52.5°</td>
<td>0.7</td>
</tr>
<tr>
<td>45°</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Notes:
- $a$ is the opening height of gate, in m;
- $D_1$ is the distance from bottom waterstop of gate to upstream faceplate, in m;
- $\alpha$ is the upstream inclination of bottom edge of gate (See Figure 1).

c) The downward suction may be calculated by the means of Formula (2). When the arrangement of the bottom edge of the overflow dam gate, the water gate and free flow tunnel gate in the dam meet the requirements of Figure 1, and the downstream flow state is good and the gate is well ventilated, the calculation of downward suction may be omitted:

$$P_s = p_s D_2 B_{zs}$$ .........................................................(2)

where
- $P_s$ is the downward suction, in kN;
- $D_2$ is the distance from the waterstop at the bottom edge of gate to the lower edge of the main beam, m;
- $p_s$ is the average downward suction at $D_2$ section on the bottom edge of gate, to be calculated on the basis of 20kN/m$^2$. When the flow state is good, the gate is well ventilated and the requirements for the arrangement of the bottom edge of the gate in Figure 1 are satisfied, the suction may be decreased appropriately.

6.1.3 The horizontal silt pressure applied on a gate may be calculated in accordance with Formula (3) and Formula (4). When the water-retaining face of the gate is tilted, the vertical silt pressure shall be calculated.

$$P_n = \frac{1}{2} \gamma_n h_n^2 \tan^2 \left( 45^\circ - \varphi / 2 \right) B$$ .........................................................(3)

$$\gamma_n = \gamma_0 - (1 - n) \gamma_w$$ .........................................................(4)

where
- $P_n$ is the silt pressure, in kN;
- $\gamma_n$ is the buoyant unit weight of silt, in kN/m$^3$;
- $\gamma_0$ is the dry unit weight of silt, in kN/m$^3$;
- $\gamma_w$ is the unit weight of water, in kN/m$^3$;
- $n$ is the porosity of silt;
- $h_n$ is the thickness of silt accumulated in front of the gate, in m;
- $B$ is the width of silt accumulated in front of the gate, in m;
- $\varphi$ is the internal frictional angle of silt, in ($^\circ$).
4.1.4 The impact force of floating material may be calculated in accordance with Formula (5):

\[ P_z = \frac{W_p v}{gt} \]  

(5)

where

- \( P_z \) is the impact force of floating material in kN;
- \( W_p \) is the weight of floating material in kN, which is to be determined on the basis of actual survey of floating material in the river;
- \( v \) is the flow velocity, in m/s;
- \( g \) is the gravitational acceleration;
- \( t \) is the impact time, s, to be estimated based on actual data.

6.2 Calculation of gate hoisting force

6.2.1 The hoisting force of a plane vertical gate shall be calculated in accordance with the following methods:

a) The calculation of the gate hoisting force in dynamic water shall include the calculation of the gate closing force, the holding force and the gate opening force.

1) The gate closing force shall be calculated in accordance with Formula (6). When the calculation result is a positive value, the ‘weight’ must be added (the ‘weight’ elements include the weighting block, the water column or the mechanically downward-pressing); when the calculation result is a negative value, the gate can be closed by virtue of its dead weight.

\[ F_w = n_T (T_{zd} + T_{zs}) - n_G G + P \]  

(6)

2) The holding force shall be calculated in accordance with Formula (7):

\[ F_t = n'_T G + G_j + W_s + P_x + P - (T_{zd} + T_{zs}) \]  

(7)

3) The gate opening force shall be calculated in accordance with Formula (8):

\[ F_q = n_T (T_{zd} + T_{zs}) + P_x + n'_G G + G_j + W_s \]  

(8)

4) The frictional resistance of the roller in the sliding bearing shall be calculated in accordance with Formula (9):

\[ T_{zd} = \frac{P}{R} (f_j + f) \]  

(9)

5) The frictional resistance of roll in the rolling bearing shall be calculated in accordance with Formula (10):

\[ T_{zd} = \frac{Pf}{R} \left( \frac{R}{d} + 1 \right) \]  

(10)
6) The frictional resistance of the sliding support shall be calculated in accordance with Formula (11):

\[ T_{zd} = f_2 P \]  

(11)

7) The frictional resistance of the waterstop shall be calculated in accordance with Formula (12):

\[ T_{zs} = f_3 P_{zs} \]  

(12)

where

- \( F_{w}, F_T, F_Q \) is the gate closing force, holding force and gate opening force, respectively, in kN
- \( n_T \) is the frictional resistance safety coefficient, which shall be 1.2
- \( n_G \) is the gate dead-weight correction coefficient used for the calculation of gate closing force, which shall be 0.9 to 1.0
- \( n_G' \) is the gate dead weight correction coefficient used for the calculation of holding force and opening force, which shall be 1.0 to 1.1
- \( G \) is the gate dead weight, kN (the weight of the suspender shall be included, if any); for calculation of gate closing force, the weight of the suspender shall not be included, and the floating weight may be taken as the weight of gate;
- \( W_s \) is the water load on gate, in kN;
- \( G' \) is the weight of weighting block, in kN;
- \( P_t \) is the uplift force, kN; including uplift force of bottom edge and uplift force of waterstop. The uplift force of the bottom edge may be calculated in accordance with Formula (1);
- \( P_s \) is the downward suction, in kN, which may be calculated in accordance with the Formula (2);
- \( T_{zd} \) is the frictional resistance of support, in kN;
- \( P \) is the total water pressure applied on gate, in kN;
- \( r \) is the radius of roller shaft, in mm;
- \( R_1 \) is the average radius of rolling bearing, in mm;
- \( R \) is the radius of the roller, in mm;
- \( d \) is the diameter of roller or ball of rolling bearing, in mm;
- \( f \) is the rolling frictional arm, mm, to be determined in accordance with Appendix A;
- \( T_{zs} \) is the frictional resistance of waterstop, in kN;
- \( P_{zs} \) pressure applied on waterstop, in kN;
- \( f_1, f_2, f_3 \) is the sliding frictional coefficients, to be determined in accordance with Appendix A (the minimum value shall be taken for the calculation of the holding force, and the maximum value shall be taken for the calculation of the gate opening force and gate closing force).
b) For a gate opened in static water, the calculation of its hoisting force shall involve the frictional resistance caused by the water level difference, the dead weight of gate as well as the weight of the weighting block. For emersed gates and tail water gates, the water level difference shall be no more than 1m; for submerged gates, the water level difference of 1m to 5m shall be adopted. In cases of silt or dirt sedimentation, the difference allowed may be increased appropriately based on actual situations.

6.2.2 The radial gate hoisting force shall be calculated in accordance with the following methods:

a) The closing force shall be calculated in accordance with Formula (13). When the calculation result is a positive value, the weight shall be added; when the calculation result is a negative value, the gate can be closed under its own dead weight.

\[
F_w = \frac{1}{R_i} \left[ n_r (T_{zd} r_0 + T_{zs} r_1) + P_r r_3 - n_G G r_2 \right] \tag{13}
\]

\[
W \quad T \quad z \quad 0 \quad z \quad 1 \quad t \quad 3 \quad G \quad 2
\]

b) The opening force may be calculated in accordance with Formula (14):

\[
F_Q = \frac{1}{R_2} \left[ n_r (T_{zd} r_0 + T_{zs} r_1) + n'_G G r_2 + G R_1 + P_r r_4 \right] \tag{14}
\]

\[
 Q \quad T \quad zd \quad 0 \quad s \quad 1 \quad G \quad 2 \quad j \quad 1 \quad x \quad 4
\]

where

- \( r_{0}, r_{1}, r_{2}, r_{3}, r_{4} \) are the acting arm of frictional resistance of the rotating hinge, frictional resistance of the waterstop, dead weight of the gate, uplift force and downward suction in relation to the moving centre of the radial gate, in m
- \( R_1, R_2 \) is the acting arm of the additional weight (or the downward force) and gate opening force relative to the moving centre of the radial gate, in m
- \( T_{zs} \) is the frictional resistance of the waterstop, to be calculated in accordance with Formula (12);

The meanings of other symbols are the same as above.

c) During the opening/closing of a radial gate, the acting point, direction and arm of force will change as the gate moves. Therefore, if necessary, the curve of opening/closing force may be drawn to determine the maximum value.

6.2.3 The lifting force of the trash rack shall be calculated in accordance with the following methods:

a) In static water, the lifting force may be calculated in accordance with Formula (15):

\[
F_Q \geq n'_G G + n_m m \tag{15}
\]

where

- \( F_Q \) is the lifting force of trash rack, in kN;
- \( n_m \) is the overweight coefficient of trash, which shall be 1.2;
- \( m \) is the weight of trash, kN, to be determined on the assumption that the grilles are partially blocked, and the blockage area shall be decided upon relative to the amount of trash;
- \( G \) is the dead weight of the trash rack, in kN;
- \( n'_G \) is the dead-weight correction coefficient, which shall be between 1.0 and 1.1.
b) During lifting in dynamic water, the lifting force shall be calculated in accordance with Formula (15), the impact of water level difference caused by partial blockage of trash rack shall be considered, and the water level difference selected shall not be more than 2m.

6.3 Calculation of area of the vent hole

6.3.1 For a service gate or emergency gate set up in a sluice pipe, the area of the vent hole behind the gate may be calculated in accordance with the empirical Formula (16) and Formula (17), or can be calculated in accordance with the semi-theoretical and semi-empirical Formula (18), Formula (19) and Formula (16):

\[
A_a \geq \frac{Q_a}{v_a} \tag{16}
\]

\[
Q_a = 0.09 v_w A \tag{17}
\]

\[
\beta = \frac{Q_a}{Q_w} = K(F_r -1)^{[\ln(1 + \frac{1}{b})]} - 1 \tag{18}
\]

\[
F_r = v/\sqrt{9.81e} \tag{19}
\]

where

- \( A_a \) is the sectional area of vent hole, in m²;
- \( Q_a \) is the full ventilation capacity of vent hole, in m³/s;
- \([v_a]\) is the allowable air velocity of vent hole, m/s, which shall be set as 40 m/s (or 50 m/s for a small gate);
- \( v_w \) is the flow velocity at gate orifice, in m/s;
- \( A \) is the area of conduit behind gate, in m²;
- \( \beta \) is the air-water ratio, namely the ratio between flow rate of air and flow rate of water discharged;
- \( Q_w \) is the flow rate when the gate is at a given opening height, in m³/s;
- \( F_r \) is the fradue number of cross-section of gate orifice;
- \( v \) is the average flow velocity at cross section of gate orifice, in m/s;
- \( e \) is the opening height of gate, in m;
- \( K, a, b \) is the coefficient for every section. See Appendix B.

6.3.2 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 per cent and 7 per cent 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.

6.3.3 The area of the vent hole behind a bulkhead gate shall be selected based on the specific situation, and shall not be less than the area of the charging conduit.
6.4 Type selection and calculations for the gate slot of a plane gate

6.4.1 For the type of gate slot for a plane gate in a water discharging system, the Type-I and Type-II gate slots may be selected. Their applicability and shape parameters are detailed in Table 3.

Table 3  Types, shape parameters and applicability of plane gate slots

<table>
<thead>
<tr>
<th>Type</th>
<th>Diagram</th>
<th>Parameters of geometric shape of gate slot</th>
<th>Applicability</th>
</tr>
</thead>
</table>
| I    | ![Diagram](image1) | ① Very good width-depth ratio \( \frac{W}{D}=1.6 \) to 1.8;  
② Appropriate width-depth ratio \( \frac{W}{D}=1.4 \) to 2.5;  
③ The empirical formula for the initial cavitation number of the gate slot is: \( K_i=0.38 \left( \frac{W}{D} \right) \) (this formula is applicable to \( \frac{W}{D} \) which is 1.4 to 3.5) | ① Gate slot of an emergency gate in a drainage sluice, and the gate slot of a bulkhead gate.  
② Gate slot of a service gate on top of an overflow dam of which the water head is lower than 12 m.  
③ Gate slot of an emergency gate or quick shutoff gate at the water inlet of a power station.  
④ Gate slot of a service gate in a drainage sluice, where the flow cavitation number, \( K \), is more than 1.0 (approximately equivalent to the situation when the water head is lower than 30 m or the flow velocity is less than 20 m/s). |
| II   | ![Diagram](image2) | ① Appropriate width-depth ratio \( \frac{W}{D}=1.5 \) to 2.0.  
② Very good offset ratio \( \frac{\Delta}{W}=0.05 \) to 0.08.  
③ Very good slope ratio \( \frac{\Delta}{X}=1/10 \) to 1/12.  
④ Very good fillet radius \( R=30 \text{m} \) to 50 m or rounded corner ratio \( R/D=0.10 \).  
⑤ The initial cavitation number of the gate slot is \( K_i=0.4 \) to 0.6 (to be selected based on existing research results and experience of similar projects). | ① Gate slot of a service gate in a drainage sluice, where the flow cavitation number, \( K \), is more than 0.6 (approximately equivalent to the situation when the water head is 30 m to 50 m, or the flow velocity is 20 m/s to 25 m/s).  
② Gate slot of an emergency gate with high water head and short conduit, of which the flow cavitation number, \( K \), is more than 0.4 and less than 1.0.  
③ Gate slot of a service gate which must frequently be opened partially and of which the flow cavitation number, \( K \), is more than 0.8.  
④ Gate slot of a service gate on top of an overflow dam of which the water head is lower than 12 m and the flow cavitation number, \( K \), is more than 0.8. |

6.4.2 If the structure near the gate slot has a special shape or the flow state is complicated, or if the service gate is required to frequently be partially open and the above-mentioned two types of slots cannot meet the needs, an appropriate type of gate slot can be selected by reference to operational experience from completed projects and through hydraulic model testing; this enables reasonable measures or methods to increase the flow cavitation number, \( K \), in the gate slot to be determined.
6.4.3 When the flow cavitation number, $K$, is less than 0.6 (approximately equivalent to a situation where the waterhead is higher than 60m or the flow velocity is more than 30m/s), the Type-II gate slot or another special type of slot shall be selected. Based on the specific conditions of the project, the lining shall be made of steel plate or low-water-cement-ratio high-strength concrete or other corrosive-resistant materials; these should be applied to areas on the upstream and downstream sides of the gate slot. During construction, the shape shall be maintained accurately and the surface shall be plane.

6.4.4 The flow cavitation number, $K$, may be calculated by using Formula (20):

$$K = \frac{\left(P_1 + P_a - P_v\right) / \gamma}{v^2 / (2g)}$$  \hspace{1cm} (20)

where

- $P_1$ is the average pressure on the cross section immediately adjacent to the upstream side of the gate slot, in kPa;
- $P_a$ is the atmospheric pressure, in kPa. See Figure 2;
- $P_v$ is the saturated vapour pressure of water, in kPa. See Figure 3;
- $\gamma$ is the unit weight of water, in kN/m$^3$;
- $v$ is the average flow velocity on the cross section immediately adjacent to the upstream side of the gate slot, in m/s;
- $g$ is the gravitational acceleration, in m/s$^2$.

Figure 2 - Curve for relationship between atmospheric pressure and elevation
6.4.5 Based on the flow cavitation number, $K$, near the gate slot, the appropriate type of gate slot may be selected. If $K_i < K$, then this type of gate slot will not generally cause cavitation. For a safety allowance for $K > K_i$, the safety coefficient $n = 1.2$ to $1.5$ may be selected based on the importance and operating conditions of the gate, so as to ensure that $K \geq nK_i$.

### 7 Anti-corrosion of hydro mechanical structures

#### 7.1 General requirements

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

7.1.2 The following three measures may be adopted for the anti-corrosion of hydro mechanical structures:

a) Anti-corrosion coating;

b) Sprayed metal anti-corrosion coating;

c) Sacrificial anode cathodic anti-corrosion protection;

7.1.3 The surface of hydro mechanical structures should be pretreated before coating.

7.1.4 The design documents shall clearly set out the surface cleanliness and surface roughness.

7.1.5 The surface pretreatment and quality assessment of steel should comply with the provisions of ISO8501, ISO8502, ISO8503 and ISO8504.

#### 7.2 Coating protection

7.2.1 The anti-corrosion coating should be composed of primer, intermediate paint and a finishing coat. The primer shall have good adhesive force and rust resistance, the intermediate paint shall have shielding performance and be effectively bonded with the primer and finishing coat, and the finishing coat shall have weather and water resistance.
7.2.2 The coating system shall be selected based on the surrounding environment.

7.3 **Sprayed-metal anti-corrosion coating**

7.3.1 The sprayed metal anti-corrosion coating system may include sprayed-metal coating and sealing coating layer. The hot sprayed metal and coating protection system shall be applied with intermediate paint and finished after the coating is sealed.

7.3.2 The metal wires used for hot spraying shall be clean and free of rust, oil or fold marks, and the wire diameter should be less than 3.0mm.

7.3.3 In the sprayed-metal coating protection system, the thickness of the metal coating shall be decided based on the environmental factors.

7.3.4 The sealing coating shall be compatible with a sprayed metal coating, have relatively low viscosity and having certain corrosion resistance.

7.4 **Sacrificial anode cathodic anti-corrosion protection**

7.4.1 Before design of sacrificial anode cathodic protection, the following data shall be collected and, if necessary, an on-site survey shall be carried out:

a) Data about the design and construction of the hydro mechanical structures;

b) Types, conditions and service life of the coating on the surface of the hydro mechanical structures;

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

d) Chemical composition, PH value, resistance rate, contamination degree of the medium and variations of temperature, flow velocity and water level;

7.4.2 The sacrificial anode cathodic anti-corrosion protection shall be used together with coating protection.

7.4.3 The hydro mechanical structures applied with sacrificial anode cathodic protection shall be insulated from the other hydro mechanical structures in the water.

7.4.4 The actual service life of the sacrificial anode cathodic protection system shall be determined based on the design service life or the maintenance period of the dry structure.

8 **Workload of hydro mechanical structures**

The summarized contents of workload of hydro mechanical structures shall include:

a) Name, specification, type, orifice size, design water head and weight of the trash rack, trash rack groove, gate and gate slot;

b) Name, specification, type and quantity of trash remover and hoisting equipment, hoisting capacity, delivery head for hoisting operations, distance of the lifting points, and the power and weight of the matching motor.

c) For a gantry hoist or a platform hoist, the span, wheel track, track model and track length of the hoist shall also be stated.
### Appendix A
(Informative)

**Frictional coefficient**

<table>
<thead>
<tr>
<th>Table A.1 - Frictional coefficient</th>
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<tbody>
<tr>
<td><strong>Type</strong></td>
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<tr>
<td>Sliding frictional coefficient</td>
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<tr>
<td>Frictional coefficient of sliding bearing</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Frictional coefficient in stagnant water</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td>Acting arm of rolling friction force</td>
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</tbody>
</table>

**NOTE** The roughness $R_a$ of the work face of the track shall be at least 1.6μm, and the roughness $R_a$ of work face of slideway shall be at least 3.2μm.
Appendix B  
(Informative)  
Semi-theoretical and semi-empirical formula coefficient

Table B.1 - Semi-theoretical and semi-empirical formula coefficient

<table>
<thead>
<tr>
<th>Type of pipe</th>
<th>Section No.</th>
<th>Length of conduit behind gate</th>
<th>Net height of conduit</th>
<th>Scope of $F_r$</th>
<th>$\beta = K(F_r - 1)^{\left(\ln(F_r - 1)+a\right)} - 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure conduit equipped with plane gate</td>
<td>I</td>
<td>6.10~10.66</td>
<td>3.96~20.30</td>
<td>1.158</td>
<td>0.112</td>
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<tr>
<td></td>
<td></td>
<td>3.87~3.960</td>
<td>1.0154</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>10.66~27.40</td>
<td>1.94~6.290</td>
<td>1.0150</td>
<td>0.035</td>
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<tr>
<td></td>
<td></td>
<td>1.61~1.940</td>
<td>1.0152</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>27.40~35.78</td>
<td>1.91~17.190</td>
<td>1.042</td>
<td>0.039</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.38~1.910</td>
<td>1.0413</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>35.78~77.00</td>
<td>1.08~15.670</td>
<td>1.1300</td>
<td>0.028</td>
</tr>
<tr>
<td>Non-pressure conduit equipped with radial gate</td>
<td>V</td>
<td>6.10~10.66</td>
<td>4.57~32.590</td>
<td>1.342</td>
<td>0.173</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.49~4.570</td>
<td>1.0153</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>VI</td>
<td>10.66~27.40</td>
<td>1.70~18.06</td>
<td>1.0540</td>
<td>0.019</td>
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<td></td>
<td>1.56~1.70</td>
<td>1.0515</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>VII</td>
<td>27.40~35.78</td>
<td>2.45~10.81</td>
<td>1.073</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td>VIII</td>
<td>35.78~77.00</td>
<td>2.33~8.310</td>
<td>1.170</td>
<td>0.182</td>
</tr>
</tbody>
</table>