



UNITED NATIONS  
INDUSTRIAL DEVELOPMENT ORGANIZATION



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

**Part 4: Civil Works and Hydro  
Mechanical Structures**

**SHP/TG 004-1: 2019**



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**Part 1: Civil Works and  
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Further recommendations and suggestions for application for the update would be highly welcome.

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## Foreword

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

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

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

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

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

## Introduction

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

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

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

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



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

## Part 1: Civil Works and Hydro Mechanical Structures

### 1 Scope

This Part of the Construction Guidelines stipulates the general principles, construction conditions, operating methods, working procedures, technological requirements, and quality standards for civil works and hydro mechanical structures according to construction characteristics of small hydropower (SHP) stations.

### 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 Construction survey

#### 4.1 Basic requirements

4.1.1 The construction survey for SHP projects should meet the following requirements:

- a) At the preparatory stage of construction and in the construction process, the following surveys shall be conducted:
  - 1) Checking survey data especially some important parameters such as axial pillars of main hydraulic structures (dam or sluice), centreline pillars (centreline of generating units), and

triangulation station pillars. If the accuracy of the survey cannot meet the requirements or any problem is found, a calibrating survey or an intensive survey shall be conducted or re-done if necessary.

- 2) During the construction process, the position and elevation of hydraulic structures shall be measured at different construction stages. Procedures such as excavation, formwork erection, filling and installation of hydro mechanical structures and electromechanical equipment shall be conducted after the survey data has been checked out.
- 3) Specialized technical design of planimetric and topographic control surveys should be carried out for a hydraulic tunnel whose length is greater than 1 km.

4.1.2 The construction plane and elevation control network system should be consistent with the coordinates and elevation system defined at the planning and design stage. A coordinates and elevation system that is converted from the same as defined in the planning and design stage may be established as required. The construction plane and elevation control network should be jointly surveyed with adjacent control points, and the joint survey precision should be no lower than the first-class engineering control requirements.

4.1.3 Before construction surveying is carried out, the work unit shall collect design documents and construction drawings and put forward the construction survey scheme.

4.1.4 All kinds of instruments and equipment used in construction survey shall be calibrated by a statutory measurement organization and used within the validity period of calibration.

## 4.2 Planimetric control surveys

4.2.1 Planimetric control networks can be established by satellite positioning (Global Positioning System or GPS), traverse or triangulation surveys.

4.2.2 Main technical requirements of satellite positioning surveys are as follows:

- a) GPS network for construction of SHP stations should be consistent with accuracy of adjacent points, as required in Table 1.

**Table 1 GPS network accuracy classification**

Item	Fixed error (a) /mm	Ratio error Factor (b) /(mm/km)	Relative mean error of the weakest side
Technical requirements	≤10	≤20	≤1/20 000
	≤10	≤40	≤1/10 000

- b) Fixed errors and proportional errors should be used in baseline survey of GPS network. The ac-

tual average side length should be used and mean square errors in baseline length should be calculated by the means of the Formula (1).

$$\sigma = \sqrt{a^2 + (bD)^2} \dots\dots\dots( 1 )$$

where

$\sigma$  is the square error in baseline length, in mm;

$a$  is the fixed error, in mm;

$b$  is the ratio error factor, in mm/km;

$D$  is the average side length, in km;

- c) Technical requirements for GPS measurement shall be consistent with the requirements of Table 2.

**Table 2 GPS measurement technical requirements**

Item	Technical requirements
GPS receiver type	Double frequency or single frequency
Number of receivers for synchronous observation	≥2
Satellite elevation angle/(°)	≥15
Number of effective satellites observed at the same time	≥4
Observation period number	≥1
Observation time/min	≥30
Interval between two data observations/s	10~30
Point geometric figure intensity factor or Positional dilution of precision (PDOP)	≤8
<p><b>NOTE</b> The number of observation periods (≥1.6) refers to at least one observation period per station when the network observation mode is adopted, and the number of secondary stationings is not less than 60% of the total number of GPS network points.</p>	

**4.2.3** The triangular network setting shall meet the following technical requirements:

- a) Accuracy matching of angle measurement and edge measurement should meet the requirements of the Formula (2):

$$\frac{m_{\beta}}{\sqrt{2} \rho} = \frac{m_s}{s \times 10^3} \dots\dots\dots( 2 )$$

where

$m_{\beta}$  is the mean square error of angle in the control network, in (");

$m_s$  is the mean square distance error, in mm;

$S$  is the length of the measuring edge, in m;

$\rho = 206\,265''$ .

- b) Technical indicators shall be consistent with the requirements in Table 3.
- c) The instrument height and prism height (target height) are taken with an accuracy of 1 mm.
- d) One-way ranging with different time periods can be used to replace closed traverse measurement.

**Table 3 Triangulation network technical requirements**

Item	Average side length /m	Mean square error of angle /(")	Triangulation maximum closing difference /(")	Relative error of average side length	Number of measuring rounds						
					Side length	Horizontal angle			Zenith angle		
						Class 0.5"	Class 1"	Class 2"	Class 0.5"	Class 1"	Class 2"
Technical requirements	100~500	±5	15	1 : 50 000	2 (in back and forth)	1	2	4	1	1	2

**NOTE** One measuring round of electro-optical distance measurement means that collimating once and obtaining four readings

4.2.4 Technical indicators of electro-optical distance measurement shall be consistent with the provisions in Table 4.

**Table 4 Measurement technical requirements for electro-optical distance measuring wires**

Item	Total length of wire /km	Average side length /m	Azimuth closure difference /(")	Mean square distance error /(")	Mean square distance error /mm	Relative closing error of longest side	Number of measuring rounds						
							Side length	Horizontal angle			Zenith angle		
								Class 0.5"	Class 1"	Class 2"	Class 0.5"	Class 1"	Class 2"
Technical requirements	2.0 2.4 3.0	200 300 500	± 10√ <i>n</i>	± 5.0	± 10 ± 10 ± 7	1 : 18 000 1 : 20 000 1 : 25 000	2 (back and forth)	1	2	4	1	1	2

4.2.5 Horizontal angle observations should comply with the following requirements:

- a) Directional observations should be used for horizontal angles. Main technical requirements for directional observations should meet the requirements in Table 5.

**Table 5 Main technical requirements for horizontal angle directional observations**

Item	Instrument type	Two random reading error of optical micrometre /(")	Two collimating reading difference /(")	Closure error of round in a semi-measuring round /(")	Range of one measuring round 2C /(")	Mutual deviation of values between measuring rounds in the same direction /(")
Technical requirements	Class 1"	1	4	6	9	6
	Class 2"	3	6	8	13	9
	Class 6"	—	12	18	—	24

**NOTE** When the perpendicular angle of the observation direction exceeds  $\pm 3^\circ$ , the range of one measuring round 2C in this direction compared with the values in the same direction in adjacent measuring rounds, the difference still complies with the provisions of this table.

- b) After the horizontal angle is observed, the mean square error of angle should be calculated according to the Formula(3), (4) and (5).

- 1) Mean square error of angle in the triangular net:

$$m_\beta = \pm \sqrt{\frac{[WW]}{3n}} \dots\dots\dots ( 3 )$$

- 2) Calculations of mean square errors of angle in the traverse network include:

- The one based on closure error of left and right angles:

$$m_\beta = \pm \sqrt{\frac{\Delta\Delta}{2n}} \dots\dots\dots ( 4 )$$

- The one based on closure error of wire azimuth:

$$m_\beta = \pm \sqrt{\frac{1}{N} \left[ \frac{f_\beta^2}{n} \right]} \dots\dots\dots ( 5 )$$

where

$W$  is the closure error of triangle, in (");

$\Delta$  is the difference between the sum of the left and right angles and  $360^\circ$ , in(");

$f_\beta$  is the azimuth closure of connecting traverses (or closed traverses), in (" );

$n$  is the number of triangles or number of stations for calculating  $f_\beta$ ;

$N$  is the number of connecting traverses or closed traverses.

4.2.6 Electro-optical distance measurement (EDM) should meet the following requirements:

a) Technical requirements for EDM shall comply with the requirements in Table 6.

Table 6 Technical requirements for electro-optical distance measurement

Item	Meteorological data measurement				Reading range of one measuring round /mm	Inter-measurement range /mm	Roundtrip or optical section range /mm
	Minimum temperature reading /°C	Minimum air pressure reading /Pa	Measurement time interval	Data acquisition			
Technical requirements	1.0	100	Measured once for each side	Observed value at the station terminal	5	7	$2(a + bD)$
<p><b>NOTE 1</b> Calculate the slope distance on the same elevation plane and then compare the round-trip range.</p> <p><b>NOTE 2</b> <math>a</math>—fixed error, mm; <math>b</math>—proportional error coefficient, mm/km; <math>D</math>—ranging length, km.</p>							

b) The accuracy of the measuring distance should be calculated according to the Formula(6) and (7);

1) Observation value error in one measurement:

$$m_D = \pm \sqrt{\frac{[Pdd]}{2n}} \dots\dots\dots ( 6 )$$

Mean square error in average value of reciprocal observations:

$$m_{\bar{D}} = \pm \frac{1}{2} \sqrt{\frac{[Pdd]}{2n}} \dots\dots\dots ( 7 )$$

where

$d$  is the range of horizontal distance for round-trip measurements on each side, in mm;

$n$  is the number of sides to be measured;

$P$  is the prior weight of distance measurement on each side. If  $P = \frac{1}{m_D^2}$ ,  $m_D$  can be calculated according to the nominal accuracy of the rangefinder.

c) Mean square distance error on either side should be calculated according to the Formula(8) :

$$m_{si} = \pm m_D \sqrt{\frac{1}{P_{Di}}} \dots\dots\dots ( 8 )$$

where

$P_{Di}$  is the prior weight of length measurement on the  $i_{th}$  side

**4.3 Altimetric control survey**

4.3.1 Levelling, EDM trigonometric levelling, or GPS fitting elevation can be used in altimetric control network survey.

4.3.2 The accuracy of altimetric control survey should meet the following requirements: the mean square error of elevation between the last elevation control point and the first elevation control point should not be greater than  $\pm 10$  mm for concrete structures nor greater than  $\pm 20$  mm for earth-rock structures.

4.3.3 Leveling should meet the following requirements:

a) Main technical requirements for levelling shall meet the requirements in Table 7.

**Table 7 Main technical requirements for levelling**

Item		Technical requirements
Random mean square error $M_{\Delta}$ /mm		$\pm 10$
Total mean square error $M_w$ /mm		$\pm 20$
Instrument model		DS3
Levelling staff		Two-sided ruler
Observational method		Abstract numeration
Levelling observation		One way
Observation order		Front and Back
Round-trip measurement range and route closure error/mm	Plateau (hilly area)	$\pm 30 \sqrt{L}$
	Mountainous region	$\pm 10 \sqrt{n}$
<p><b>NOTE</b> <math>n</math> is the number of one-way stations on the levelling route, and the closure error is calculated as if in the mountain area when the number of stations is more than 16 per kilometre; <math>L</math> is the length of the closed or attached route, km.</p>		

b) Technical requirements for levelling stations shall meet the requirements in Table 8.

**Table 8 Technical requirements for levelling stations**

Item	Technical requirements
Instrument model	DS3
View line length/m	$\leq 150$
Front and rear sight distance difference/m	Roughly equal
Front-and rear sight distance difference/m	$\leq 10$
Lowest height to the ground/m	Three-wire reading
Repeated measurement times of digital level/time	$\geq 1$
Basic and auxiliary partition (black, red) reading range/mm	3.0
Basic and auxiliary partition (black, red) heightening range/mm	5.0
<p><b>NOTE</b> The number of repeated measurements for the phase-method based digital level can be represented by deducting 1 from the value in the table. When ground vibrations are large, all digital levels should stop measuring until the vibrations vanish. The number of repeated measurements should be increased at any time when vibrations are unavoidable.</p>	

c) When the levelling routes go across rivers, lakes, depressions, valleys and other barriers, and the observation station viewline length exceeds the requirements in Table 8, the requirements in Table 9 shall be met.

**Table 9 Technical requirements for river-crossing levelling stations**

Item	Instrument model	Viewline length /m	Frequency of instrument height changes/time	Two altitude difference range /mm
Technical requirements	DS3	$\leq 200$	1	$\leq 7$

4.3.4 Technical requirements for EDM trigonometric levelling shall meet the requirements in Table 10.



Table 10 Measurement technical requirements for EDM trigonometric levelling

Item	Maximum side length/m			Number of slant-range measurements	Zenith distance observation				Accuracy measurement of instrumental height and prism height/mm	Reciprocal observation elevation range/mm	Two times of height difference on view for every other site station setting /mm	Closure error of connecting traverse or loop wire /mm	
	Instrument	Unidirectional	Opposite direction		Number of measuring rounds		Index difference range /(")	Measurement difference /(")					
					Central wire	Three-wire							
Technical requirements	DJ3	1 000	800	500	2	2	1	10	10	$\pm 2$	$\pm 70D$	$\pm 20 \sqrt{D}$	$\pm 30 \sqrt{L}$

**NOTE**  $D$  is horizontal distance, km;  $L$  is the total length of the line, km; one measuring round of slope distance is collimating once and measuring the distance for 4 times, and meteorological data is read at the same time.

4.3.5 GPS elevation fitting surveying should be conducted together with planimetric control surveying and can be applied in plains or hills. The main technical requirements shall meet the following specifications:

- The GPS points of the connection survey should be distributed around and at the centre of the survey area. For a zonal survey area, the GPS points shall be distributed at the two ends and the centre of the area.
- The points of the connection survey should be more than 1.5 times the number of unknown parameters in the selected calculation model. The spacing of points should be less than 10 km.
- In an area with large height differences, the points of the connection survey shall be increased.
- In varied topography areas, the method of sub-regional fitting should be adopted.

#### 4.4 Construction and installation survey

4.4.1 The measuring accuracy during the excavation stage shall meet the requirements of Table 11.

**Table 11 Mean square error of the location of the excavation contour points**

Projects	Mean square error of point location (mm)		Note
	Planimetric	Altimetric	
Basic contour points and positioning points of pre-split blast holes of major projects	$\pm 50 \sim \pm 100$	$\pm 100$	Only refers to the parts with dense rebar. Mean square error of point location is incomparison to adjacent control points or observation station points, and axis points with an error of $\pm 50$ mm
Top points, middle points of main projects, basic contour points of non-major projects	$\pm 100$	$\pm 100$	
Excavation contour points of the overburden of soil, sand and rock	$\pm 200$	$\pm 200$	

4.4.2 The measuring accuracy during the stages of formwork erection, pouring and filling shall meet the requirements of Table 12.

**Table 12 Mean square error of the location of the contour points of formwork erection and filling**

Material	Structures	Mean square error of the point location (mm)		Error distribution of planimetric position (mm)	
		Planimetric	Altimetric	Axis points (points of observation stations)	Measurement of detail
Concrete	Shafts, surge cambers of main hydraulic structures (dams, sluices, plants), ship locks and discharge structures	$\pm 20$	$\pm 20$	$\pm 17$	$\pm 10$
	Other holes in guide walls, the lining of wells and tunnels, dams	$\pm 25$	$\pm 20$	$\pm 23$	$\pm 10$
	Other structures (auxiliary dams, coffer-dams, core walls, aprons, revetments, retaining walls)	$\pm 30$	$\pm 30$	$\pm 25$	$\pm 17$
Earth-rock materials	Upstream and downstream side lines of roller compacted dams. Observation holes of face core wall dams and rock-fill dams	$\pm 40$	$\pm 30$	$\pm 30$	$\pm 25$
	Positioning points of equipment in the dam and the dividing line of filling	$\pm 50$	$\pm 30$	$\pm 30$	$\pm 40$

4.4.3 The vertical measuring deviation of concrete placement and the installation of prefabricated components in high buildings shall meet the requirements of Table 13.

Table 13 Limits of the deviation of the altimetric survey

Projects	Deviation of the abutting centre lines of two adjacent layers (mm)	Relative deviation of the base centre line (mm)	Cumulative deviation (mm)	Note
Framework and stand columns of powerhouses and switchyards	$\pm 3$	$H/2\ 000$	$\pm 20$	<i>H</i> is the total height
Side walls of piers, trestle piers, ship locks, powerhouses	$\pm 5$	$H/1\ 000$	$\pm 30$	

4.4.4 After erection, the formwork of buildings shall be checked by contour points, and the deviation shall meet the requirements of Table 18.

## 5 Construction diversion

5.1 The construction diversion shall meet the following requirements:

- a) The diversion system shall properly solve water retention and water release problems from the initial stage to the later stage, and deal well with the any conflict between flooding and construction.
- b) The design standard of the diversion system shall be decided according to the approved design documents. When it is difficult to build the diversion system according to the standard, based on full explanation and approval from departments in charge, the standard can be appropriately lowered. However, river and weather forecasting shall be strengthened. Before the flood season, the project shall comply with the safety standard for flood passage.
- c) Problems such as navigation, log passing, supplying water downstream and discharging ice shall be properly solved during the entire construction process according to the design provisions approved by the departments in charge.
- d) The emergency plan for the time when the natural river inflow exceeds the design flood standard shall be drawn up and submitted to the relevant departments for approval.

5.2 Cofferdam construction shall meet the following requirements:

- a) The construction and removal schedule of the cofferdam shall comply with the total construction schedule. The construction of the diversion and discharge structures shall be carried out in coordination with that of the cofferdam body and anti-seepage body, and the cofferdam shall reach the design elevation before the flood season.

- b) The planning of building materials, stockyard and filling of roads shall be well prepared while the usage of materials is optimized. The materials from excavation of foundation of permanent buildings shall be fully used. The planned filling volume of the weir body should not be less than 150% of the estimated amount. Cofferdam should be combined with permanent buildings.
- c) Attention shall be paid to the treatment of dam foundation seepage prevention. The seepage treatment of the cofferdam foundation covering layer shall be safe, reliable, simple and practicable.
- d) The cofferdam removal shall meet the design requirements. Rocks and sundries used to build the cofferdam shall be cleaned up. The removal range and removal section (width and height) shall meet the operational requirements of the permanent structures. The removal of the first-stage cofferdam in stages shall meet the diversion and discharge requirements of the second-stage cofferdam.
- e) The possibility of the foundation pit flooding during diversion should be considered.

**5.3** The river closure construction shall meet the following requirements:

- a) Before river closure, the closure design standard shall be determined and careful design shall be carried out, and river forecasting shall be properly done, and the manpower, material and technical resources shall be well prepared.
- b) The river closure time shall be determined based on a comprehensive analysis of the hydrology, weather, river channel usage, actual schedule of the preparatory projects and the strength of the cofferdam and foundation pit before the flood season.
- c) The vertical closure method shall be adopted for the river closure.
- d) For river beds where the foundation is not rock, riprap bottom protection shall be finished beforehand in the entire river gap and critical sections. The length of the downstream protection slope of the closure dike shall be taken as 2 to 4 times the average water depth at the gap, and the value upstream shall be taken as 1 to 2 times the maximum water depth. Series connection rocks and anchoring rocks can be used to throw into the gap. The total volume of closure preparation materials shall be estimated according to the comprehensive factors of stockpiling condition, transport condition, possible loss amount, and closure dike settlement. The actual preparation volume can be appropriately increased, with a coefficient of 0.2 to 0.3 for the increase.
- e) During the closure process, the hydraulic characteristics shall be regularly measured to modify the rock types to be used and throwing strength, and to improve placement methods.
- f) Materials used in the closure sealing shall be prepared to ensure the quality of the closure sealing. When stones are used to seal, the sealing materials shall be filled in accordance with the

principle of filling the inverted filter layer at the upstream slope. The filling materials indifferent layers shall be laid steadily and uniformly. Before the closure sealing, oil cloth, canvas and geosynthetics can also be used. For rivers with a heavy silt load, silt-accumulation either manually or by colmation (clogging through retention) can be chosen as the sealing method.

#### 5.4 Anti-flood measures shall meet the following requirements:

- a) When the dam top filling elevation exceeds the cofferdam top elevation, the temporary flood control design standard for the dam body shall be reasonably determined according to the dam type and the storage capacity in front of the dam.
- b) Before the flood season, structures affected by floods shall comply with the design requirements for flood passing elevation and profile.
- c) Except for concrete-faced rockfill dams, the upstream cofferdams for earth and rockfill dams should all be part of the dam body as much as possible, so that the dam body meets the first flood passage.
- d) For concrete-faced rockfill dams, when the concrete faceplate is not fully formed, the upstream dam slope shall be reinforced with rolling mortar or jetting cement mortar or concrete extrusion side wall. Then the dam body can withstand floods during the flood season. If overflow through the dam body is used, the dam surface and the downstream dam slope shall be reinforced with large-sized boulders or reinforced stone cages.
- e) For concrete dams and masonry dams, whether an entire section cofferdam or staged cofferdam is adopted, river diversion can be done by using the temporary section of the dam body, pre-formed bottom holes and gaps, or in combination with other discharge structures.
- f) The powerhouse can use a cofferdam or the temporary section of the dam body to form a small foundation pit for the passage of floods. When the powerhouse structure is used to retain flood waters, the stability and stress of the powerhouse building shall be checked, and the water intake and the draft tube outlet shall be plugged properly.
- g) Before cofferdam removal, the area protected by the cofferdam shall be cleaned up.

#### 5.5 Construction for the plugging of diversion structures shall meet the following requirements:

- a) The closure of diversion structures shall not be carried out until the structural profile has reached the design standard of closure, reliable flood control and flood discharge measures are available, the requirements of ecological water use in the lower reaches can be met, and the project has been inspected and accepted for water storage by the competent authority.
- b) The plugging of downstream sluices shall be finished during the dry period. Appropriate time

and design flow for gate closure should be selected to leave sufficient time for closing gates to ensure safe operation and evacuation.

- c) The plugging measures can adopt sluice gate plugging or cofferdam plugging. The adopted measure can be determined by construction requirements and project conditions.
- d) The plugging construction shall meet the design requirements, and ensure the construction quality and schedule. The plug shall meet the requirements for stability, cracking resistance, combining closely with surrounding rock or old concrete, and impermeability. The plug should be constructed in sections and the length of each section should be 10 m to 15 m. Grouting tubes and water-cooled tubes should be built into the plug, and grouting and cooling galleries can be set up, if necessary. Low-heat low-expansion cement or externally mixed magnesia concrete can also be used. The casting layer thickness should be 1.5 m. If the temperature reaches the mean annual temperature, contact grouting shall be applied. Before the plug is sealed, the dike rock at the plug top section shall be properly treated according to the design.

**5.6** The foundation pit drainage shall meet the following requirements:

- a) The foundation pit drainage is divided into initial drainage and regular drainage, and shall meet the following requirements:
  - 1) In order to keep the cofferdam and foundation stable, the water level drop rate in the foundation pit should be controlled to be within 0.5 m/day to 1.0 m/day during the initial drainage stage. The capacity of the drainage equipment for the foundation pit can be determined by trial.
  - 2) Before the excavation begins, the drainage system shall be carefully arranged and the drainage equipment shall be properly selected. The arrangement of the drainage system shall be designed to be used during both the foundation excavation and the construction of the main structure.
- b) If the building foundation is placed on permeable soft soil or fine sand layers, then during foundation excavation the method of lowering the groundwater table manually shall be adopted.

## **6 Basic regulations for civil works construction**

### **6.1 Excavation and filling of earth and rock**

**6.1.1** Before earthwork, special construction schemes should be worked out for earth and rock works involving risks beyond a certain scale, and experts should be consulted to examine and suggest the special construction schemes for such earth and rock works.

6.1.2 Soft foundation excavation shall meet the following requirements:

- a) The soft foundation excavation scheme shall be optimized, with correct dewatering and drainage measures, thorough calculation for excavation-filling balance and proper allocation of resources.
- b) The pit slope shall be determined after stability checking according to engineering geological and hydrogeological conditions, dewatering measures, and site conditions. Slope stability protection measures, and a practical and effective contingency plan shall also be formulated.
- c) Before excavation, the groundwater level shall be lowered to 0.5 m below excavation level.
- d) Foundation pit shall be excavated from top to bottom, by layered, segmented, and zoned procedures in a proper order. Drainage ditches should be set by layers and be excavated downwards layer by layer.
- e) A protective layer of a certain thickness, 0.3 m to 0.5 m, should be left at the bottom of the foundation pit, according to the soil, meteorological, and construction equipment conditions. Before starting construction work at the bottom, excavation is done block by block.
- f) Hydraulicking (hydraulic excavation) is applicable to siltstone, fine sand, sandy loam, middle and light loam, silty soil and cohesive soil prone to disintegration.
- g) For sub-zero temperatures, reliable anti-freezing measures shall be implemented immediately after excavating the protective layer.
- h) If geological conditions are not in accordance with the design conditions, treatment measures shall be considered jointly with relevant organizations. If there are cultural relics and historic sites, fossils, underground facilities or permanent markers set up by departments of mapping, geology, seismology, communication they shall be properly protected and reported to the relevant departments in time for further action.
- i) Spoil shall not hinder pit excavation and other work, or influence pit wall stability. Secondary mucking shall be avoided. Waste disposal areas shall be rationally distributed according to local conditions. They shall not worsen flow conditions or cause downstream deposits; no cultivated land, or as little as possible, should be occupied. If the construction schedule allows, spoil disposal shall be combined with land reclamation in order to help agricultural cultivation. Soil disposal should be combined with other construction work, and attention should be paid to environmental protection and recovery.
- j) Soft foundation excavation should be completed before the flood season or the ground freezes, if possible. Technical measures for ensuring engineering quality during construction during the flood season shall be spelled out in the construction planning. Before the flood season, the

worksite's drainage system shall be dredged, strengthened or built according to the local topography, in order to ensure unblocked flow and to avoid accumulation. Surface water from nearby areas must be prevented from entering the site.

- k) Excavation, storage, protection, and rehabilitation of tilled soil should meet the design requirements.

**6.1.3 Rock foundation excavation shall meet the following requirements:**

- a) The foundation shall be excavated layer by layer from top to bottom. If construction at the bank slope and river bed bottom is concurrent, safety shall be ensured. Otherwise, the bank slope shall be excavated in advance. A bottom to top excavation procedure shall not be employed if safety techniques have not been discussed or proven, or approved by the department in charge.
- b) Different methods of rock foundation excavation shall be chosen according to different stages:
  - 1) For excavation of the design slope outline, preference shall be given to the pre-split or smooth blasting method.
  - 2) Foundation rock excavation shall employ the shallow hole step blasting method, layer by layer.
  - 3) Excavation near the horizontal foundation surface shall make use of the reserved rock-mass protective layer, and employ the excavation method of layered blasting and flexible cushion layer, or horizontal pre-stressed blasting.
- c) Excavation deviation at the foundation surface shall be in accordance with the following requirements:
  - 1) For hard or medium-hard rock mass in which diacase is undeveloped, relatively developed or developed, the elevation excavation deviation of the horizontal foundation surface shall not be larger than  $\pm 200$  mm; the excavation deviation of the design slope outline surface shall not be larger than  $\pm 2\%$  of the excavation height when the depth of the boreholes is drilled in one step. For step excavation, both the deviation at the location of the step slope toe at the very bottom and the deviation of the mean slope of the whole side slope shall meet the design requirements.
  - 2) For rock mass with extremely developed diacase, soft rock mass, rock mass in unfavourable geological areas, and locations at foundation grooves and other parts with special requirements, the excavation deviation shall meet the design requirements.
  - 3) For fractured, extremely fractured, relatively soft, soft, and extremely soft rocks, rocks in unfavourable geologic sections, and other parts with special design requirements, the



excavation deviation should meet the design requirements.

- d) Mucking transportation shall meet the requirements of construction planning, and shall meet the requirements of 6.1.2.
- e) Excavation near the design level of the structure foundation, the design slope, structures, and protected objects must employ shallow hole blasting with small to medium size holes.
- f) Drilling quality shall meet the following requirements:
  - 1) The drillhole position shall be determined according to the blasting design; the drilling position deviation shall not affect or change the blasting design.
  - 2) Drilling angle and depth should meet the requirements of blasting design. The borehole angle deviation should not be greater than  $2^{\circ}$  for blast hole, not be greater than  $1^{\circ}$  for pre-splitting and smooth blasting holes; and the allowable hole depth deviation should be in the range of 0 to +200 mm for common blastholes, and be in the range of  $\pm 50$  mm for pre-splitting and smooth blasting holes.
  - 3) Drill cuttings (broken bits of solid material) in already drilled holes shall be removed before charging. Orifices shall be properly protected. After passing hole inspection, charging work may be carried out.
- g) Pre-split and smooth blasting shall meet the following requirements:
  - 1) For blasting effect, not only the excavation deviation stipulated in Item c) of this paragraph, but also the following requirements shall be complied with:
    - Residual blasthole traces shall be distributed evenly on the excavation surface.
    - The preservation rate of residual blasthole traces shall be greater than 80% for rock mass with undeveloped diaclose, 50% to 80% for rock mass with relatively developed and developed diaclose, and 10% to 50% for rock mass with extremely developed diaclose.
    - Unevenness of the rock surface between two adjacent blastholes shall not be greater than 200 mm.
    - There shall be no obvious blasting fissures in the blasthole wall.
  - 2) Pre-split blasting parameters for inclined and vertical foundation surfaces may be determined by referring to Appendix B according to engineering practice, and be verified and adjusted in field tests in order to ensure effectiveness of the pre-splitting. Smooth blas-

ting parameters shall also be determined by test according to geological condition, or by referring to empirical data of similar projects.

- 3) For pre-split blasting on the design foundation surface of key hydraulic structures, the pre-split range shall exceed the bench blasting area.
    - If pre-split holes are parallel to the bench blasting holes, the spacing between the two should be 50% to 70% of the row distance between bench blasting holes. If pre-split holes are not parallel to the bench blasting holes, the smallest spacing between two holes at the charging location at the bottom of each hole shall not be less than  $10D$  to  $30D$  ( $D$  is the diameter of the pre-split hole).
    - When the hole bottom spacing is  $10D$  to  $30D$  and if the spacing between orifices is too large, auxiliary holes shall be drilled additionally in order to protect fracture of the upper rock, and the spacing between the bottom of the auxiliary holes and the pre-split holes shall not be less than 1.0 m.
    - The depth of the pre-split crack should be equal to the vertical failure depth of the bench hole bottom, and may be determined according to Table 14. The overlength of the two end sections of the pre-split crack should be  $100d$  to  $200d$  ( $d$  is the diameter of charge in the blasting hole). The width of the pre-split crack shall be in compliance with the following requirements: for hard rock, the width shall be 5 mm; for medium-hard and soft rock, the width should not be less than 10 mm, and shall be determined according to blasting tests.
  - 4) If pre-split and bench blast holes are in the same network at the time of detonation, the blasting of pre-split blast holes shall be done not less than 75 ms to 100 ms in advance of that for adjacent blast holes in the same bench.
  - 5) Both pre-split and smooth blasting shall employ uncoupled charging work formation, and cushioning holes may employ uncoupled charging work at intervals. Both pre-split and smooth blasting charging shall be carried out according to design requirements.
- h) Bench blasting shall meet the following requirements:
- 1) Bench blasting effect shall comply with the following requirements:
    - Lumpiness of stone ballast and blast piles shall be suitable for operation with mechanised excavators.
    - If stone ballast needs to be utilized, lumpiness or gradation shall comply with relevant requirements.

- The extent of damage from blasting to adjacent rock mass shall be small, and there shall be few blast roots at the bottom of the blasting area.
  - There shall be least vibration, air shock waves (or noise) and flyrock.
- 2) For the row of bench blastholes adjacent to the design slope, the hole and row distance, and charging quantity of each hole shall be less than that of other bench blastholes. Blasting near a trench, pit, foundation trench and permanent slope shall employ the pre-split or smooth blasting method, and cushioning holes shall be laid out between primary blasting holes and pre-split holes (smooth holes).
  - 3) If the protective layer excavation method on reserved rock mass is employed, for the upper part of the protective layer, the blasthole shall not pierce the protective layer bench.
  - 4) The maximum sectional initiating charge of bench blasting shall not be larger than 300 kg, while in the area near the design foundation surface and slope, the maximum sectional charge shall not be larger than 100 kg. For blasting near structures or protected objects, at the pit and trench parts in an underwater environment, or under conditions with special requirements. The maximum sectional charge must be determined by blasting trials.
- i) Blasting adjacent to the horizontal foundation surface shall meet the following requirements:
- 1) The protective layer thickness of rock mass near the horizontal foundation surface shall be determined by blasting tests and the tests shall be done unconditionally. Table 14 may be referred to.
  - 2) The protective layer adjacent to the horizontal foundation surface shall be excavated by the following one-time blasting method:
    - Horizontal pre-splitting blasting is adopted on the rock foundation surface, and the blasting method of horizontal hole step or shallow hole step is adopted on the upper part; Horizontal smooth blasting is carried out along the foundation surface, the upper part adopts shallow hole step blasting method;
    - When there is no water at the bottom of the hole, the step blasting method with vertical (or inclined) shallow hole and flexible or composite material cushion at the bottom of the hole can be adopted.
    - Any of the above blasting methods shall be tested and proved to be feasible before implementation.

- 3) If blasting is proved feasible, the deep-hole step one-time blasting method can also be adopted for the horizontal foundation surface. The method shall adopt the following measures:
- The horizontal pre-splitting blasting method shall be adopted for the horizontal foundation surface;
  - The blasting hole bottom of step blasting shall be at an appropriate distance from the horizontal pre-splitting surface.
- 4) Layered blasting can also be applied to the protective layer adjacent to the horizontal foundation surface.

**Table 14 Protective layer thickness of rock**

Rock mass property	Undeveloped diacalse and hard rock	Relatively developed and developed diacalse and medium-hard rock	Extremely developed diacalse and soft rock
Protective layer thickness	$25d$	$30d$	$40d$
<b>NOTE</b> $d$ is diameter of blasthole charging.			

- j) Groove blasting shall adopt the following measures:
- 1) It is advisable to excavate by layered blasting with small diameter hole, and smooth blasting or pre-splitting blasting shall be adopted around the area.
  - 2) For the groove with a width of less than 4 m, the diameter of the blasting hole shall be less than 50 mm, and the depth of the blasting hole shall be less than 1.5 m.
  - 3) The pre-splitting blasting on both sides of the groove shall not be detonated simultaneously. If the pre-splitting blasting on both sides is detonated in the same network, one side shall lag at least 100 ms.
- k) For high side slopes in unfavourable geological areas, the following requirements shall be met during excavation :
- 1) Corresponding solutions shall be proposed during excavation:
    - Anchoring shotcrete with wire mesh may be employed to strengthen the rock slope.
    - Highly weathered and soil slopes may employ concrete or masonry network with inter-

locking masonry or soil fill with anchor rods or cables being embedded at the grid points.

- The treatment methods for gravity retaining walls, slope toe weights, anti-slide piles, pre-stressed anchor rods or cables, open caissons may also be employed according to design requirements.

2) The following issues shall be paid attention to:

- A rational excavation procedure shall be chosen.
  - A rational bench excavation height shall be chosen.
  - Vibration resistance measures such as pre-splitting shall be employed.
  - Blasting parameters shall be determined rationally; the maximum amount of single charge dynamite and one-time charge amount for initial blasting must be strictly controlled.
  - For rock mass that is seriously cut and affected in part by structure, suitable excavation methods and strengthening treatment shall be considered and employed.
  - For excavated slopes, rational and effective measures shall be employed for strengthening.
  - Surface and underground drainage shall be intensified to reduce external water pressure.
- I) When blasting in the vicinity of building or newly poured concrete, the vibration velocity of particle on the building foundation surface or newly poured concrete shall not be greater than the safe permissible standard for blasting vibration, and the safe permissible standard for blasting vibration shall be determined by blasting tests, and the particle vibration velocity shall be predicted and controlled in the drilling blasting construction. If blasting is needed near the new grouting area, new pre-stressed anchorage area, new shotcrete anchor (or shotcrete) support area, it should be carried out through testing and demonstration. In special cases, it can be determined after demonstration according to the existing engineering example analogy method.

6.1.4 Earth-rock filling shall meet the following requirements:

- a) Treatment of fill for the foundation base shall meet the design requirements. After excavation reaches the design foundation base, debris and accumulated water shall be removed, and filling may not be done until foundation treatment and concealed works pass acceptance.
- b) The type, gradation, water content, size, and oversized particles of the filling earth-rock mix-

ture shall all comply with design requirements.

- c) Water content in cohesive-soil filling shall be strictly controlled.
- 1) If the natural water content of the earth material is larger than the construction-controlled upper limit of water content,
    - Interception ditches around the borrow area and cross drainage ditches within the borrow area shall be properly made.
    - Earth material shall be strewed by means of layered collection or mechanical scarification.
    - Adjustments may also be made by mixing lower water-content earth material with higher water-content earth material.
  - 2) If the natural water content of the earth material is less than the construction-controlled lower limit of water content, the water content should be regulated by adding water in the borrow area or sprinkling water on the dam surface. Any unsatisfactory earth material shall not be transported to the filling surface.
- d) Before the filling of each layer, the design size and measurement of the external side slopes for each part to be filled with material shall be set out in order to ensure that its sectional dimensions are in accordance with design requirements.
- e) Before construction, compacting equipment shall be rationally chosen according to the engineering characteristics, filler type, design compaction coefficient and construction conditions. The control range of the earth material water content shall be determined. Parameter tests of soil spreading thickness and compaction times shall also be carried out. If conditions do not permit testing, parameters may be chosen by referring to Table 15.
- f) A vibratory smooth drum is recommended to fill material made of stone ballast, debris, and pebble. When a vibratory smooth drum of 80 kN to 130 kN weight is employed for compaction, the soil spread thickness should be 0.6 m to 1.0 m, the maximum grain size shall not be greater than 2/3 of the thickness of the spreading layer, and water shall be properly sprinkled according to material quality and rock character. For rolling, static rolling should be employed first, and then vibratory rolling, and the number of times of rolling shall be determined by onsite tests (should be 4 to 6 times). For cohesive soil, static rolling should be employed.
- g) For mechanical rolling, the running speed shall be controlled according to the following requirements; no faster than 2 km/hr for smooth and vibrating rollers, and no faster than 3 km/hr for tamping rollers.

Table 15 Soil spreading thickness and compaction times for each filling layer

Compacting equipment	Soil spreading thickness for each filling layer (mm)	Compaction times for each filling layer (times)
Smooth drum (0~130 kN)	200~300	6~8 (10~12 for slag)
Tamping roller (75~160 kN)	200~350	8~16
Frog rammer (2 kN)	200~250	3~4
Manual ramming	No larger than 200	10~12
Vibrating roller (80~150 kN)	600~1 300	6~8
Plate-type vibrator	150~250	—
<b>NOTE</b> For manual ramming, grain size of soil block shall not be larger than 50 mm.		

- h) Compaction parameters shall be strictly controlled during construction. New material may not be paved on an upper layer until compaction is completed and up to standard. For sectional filling, rolling traces of two adjacent connecting zones shall overlap. The width of overlap of the connecting zone perpendicular to the rolling direction shall not be less than 0.3 m to 0.5 m, and that parallel to the rolling direction shall be 1 m to 1.5 m. Sections between upper and lower layers shall be staggered, and the distance between adjacent staggered joints shall not be less than 1 m. Two adjacent filling layers of earth material shall be properly combined. Except for compaction by spiky or bump rollers, new material shall not be paved until scarifying and water-sprinkling treatment is completed.
- i) Filling of impervious earth material shall meet the following requirements:
- 1) Impervious earth material shall be paved along the direction of the dam axis and in a timely manner. A fixed-point measurement procedure should be employed to strictly control soil spread thickness, so that over-thickness is avoided. In addition, a smoothing procedure using a motor grader should be carried out for impervious earth material structures.
  - 2) Earth material for anti-seepage bodies shall be dumped in advance, and motorised vehicles shall not travel on compacted earth material surfaces.
  - 3) Earth material for anti-seepage bodies should be compacted by vibrating bump rollers, and rolling shall be carried out along the direction of the dam axis. For special parts where rolling can only be done perpendicularly to the dam axis, then during casting, spreading and rolling, the quality inspection team shall supervise the construction onsite; over-thickness in casting, omission of compaction or insufficient compaction shall not occur.
  - 4) If the anti-seepage body is rolled section by section, and the rolling traces of two adjacent connecting zones shall overlap. The width of overlap of the connecting zone perpendicular to the rolling direction shall not be less than 0.3 m to 0.5 m, and that parallel to the rolling direction shall be 1 m to 1.5 m.

- j) During filling, enough side slope allowance shall be kept in each layer according to regulations, and the slope is cut to the design requirements section after filling to the design elevation. An allowance of 300 mm to 500 mm overfilling width of each layer should be kept.
- k) Allowance shall be made for additional sinkage of the filling according to design requirements. If no design requirement is specified, additional sinkage may be determined jointly with the design according to the nature of the engineering project, filling height, filler type, compaction coefficient, and foundation condition.
- l) Quality control and inspection shall be carried out during the entire filling procedure. Filling material inspection, water content variation detection, soil spread thickness, rolling times, joint between adjacent layers, joint treatment, dry density after compaction, and slope size shall all meet design requirements.

## 6.2 Cavern excavation

6.2.1 Construction surveys of underground caverns shall comply with the requirements of Section 4.

6.2.2 The contractor shall draw up a construction plan before cavern excavation, and report to the supervisor. Excavation cannot be carried out until the supervisor approves the plan. The plan shall include at least the following contents:

- a) Engineering status;
- b) Construction layout and auxiliary facilities;
- c) Construction methods;
- d) Construction scheduling;
- e) Allocation of project construction resources;
- f) Safety and quality control measures;
- g) Construction safety monitoring and protection;
- h) Measures for environmental protection, soil and water conservation.

6.2.3 Cavern excavation shall meet the following requirements:

- a) The underground cavern excavation method shall be chosen according to geological conditions, project scale, support procedures, construction period requirements, allocation of project con-



struction resources and construction conditions. It is advisable to adopt the “NATM” construction method. Surrounding rock classification is listed in Appendix C.

- b) Underground caverns should not be excavated with insufficient area or underbreak. The mean radial over-excavation radius shall not be greater than 200 mm for adits, and 250 mm for inclined or vertical shafts. Under poor geological conditions, the value shall be jointly determined by consultation among the proprietor, designer, supervisor and builder.
- c) During construction, effective support measures shall be employed to ensure construction safety according to engineering practice, geological conditions and construction characteristics.
- d) According to excavation and section size, the underground cavern scale may be classified into 5 types:
  - 1) Extra small section, for which the design excavation area is less than 10 m<sup>2</sup> or span is less than 3.0 m;
  - 2) Small section, for which the design excavation area ranges from 10 m<sup>2</sup> to 30 m<sup>2</sup>, or span ranges from 3.0 m to 5.5 m;
  - 3) Medium section, for which the design excavation area ranges from 30 m<sup>2</sup> to 60 m<sup>2</sup>, or span ranges from 5.5 m to 7.5 m;
  - 4) large section, for which the design excavation area ranges from 60 m<sup>2</sup> to 120 m<sup>2</sup>, or span ranges from 7.5 m to 12.0 m;
  - 5) extra-large section, for which the design excavation area is greater than 120 m<sup>2</sup> or span is greater than 12.0 m.

#### 6.2.4 Cavern entrance excavation shall meet the following requirements:

- a) Before underground excavation, the rock mass stability at the underground cavern’s entrance shall be analysed in order to determine the excavation method, support measures and slope strengthening scheme for the cavern entrance.
- b) Slope cutting at the cavern entrance shall be carried out layer by layer from top to bottom, and vertical work shall be avoided. Unstable rock at the cavern entrance side slopes shall be cleared up, and drainage facilities shall be unobstructed.
- c) Before entering the cavern, the rock mass at the tunnel-face shall be identified by all the departments involved in the construction. Enter the cavern only after its stability is confirmed.
- d) The procedure for entering the cavern and whether supports are needed are determined by the

size of the entrance section and the geological conditions.

- e) Safety measures such as a protective shed shall be set up at the cavern entrance. For unstable and extremely unstable surrounding rock of class IV or V, a certain range of the adjacent mountain body may be strengthened or an open arch made before excavation, and then the cavern entrance is excavated.

**6.2.5** Adit excavation shall meet the following requirements:

- a) For surrounding rock of classes I to III, if the tunnel excavation diameter is less than 10 m, the full face excavation method should be employed; otherwise, the step method can be employed.
- b) For surrounding rock of class IV, if the excavation section is larger than medium size, the sectional excavation method should be employed. Once excavation is completed, temporary supports shall be put in place.
- c) For surrounding rock of class V, the adit shall be excavated in compliance with the requirements of 6.2.13.

**6.2.6** Vertical and inclined shaft excavation shall meet the following requirements:

- a) For excavation of inclined shafts with a tilt angle of less than 30°, a full section from top to bottom may be employed. For inclined shafts with a tilt angle ranging from 30° to 45°, a full section from top to bottom, or excavation from bottom to top, may be employed, and if excavation from bottom to top is employed, slag skimming and sliding measures shall be implemented. For inclined and vertical shafts with a tilt angle greater than 45°, the method of excavating a pilot shaft from bottom to top before extending excavation from top to bottom, or the full face excavation method may be employed.
- b) If a vertical or inclined shaft is excavated by the top to bottom method, its wellhead shall be securely locked to ensure wellhead stability and to avoid sundry materials falling in; if poor geological conditions are encountered, supports shall be set up in time.
- c) If excavation is extended from top to bottom after a pilot shaft is connected through, the above-mentioned requirements shall be complied with; furthermore, effective measures shall be implemented to avoid pilot shaft blocking and people accidentally falling in.
- d) For excavating a small-section vertical shaft in surrounding rock of classes I and II, full face excavation may be implemented from bottom to top, employing the cage raising or climbing method, or inverse well drilling method.
- e) For surrounding rock of classes I and II, excavation of vertical shafts with sections larger than medium size may employ the method of extending excavation from top to bottom after excava-

ting a pilot shaft, and the pilot shaft section should range from 4 m<sup>2</sup> to 5 m<sup>2</sup>.

**6.2.7** Excavation at special locations including underground powerhouse crane beams on a rock ledge, bench crane beams in rock, high pressure branch pipes, skewback and adjacent side walls, rock plugs, and cavern entrance excavation at previously formed high walls shall meet the following requirements:

- a) Excavation at special locations shall be specially designed.
- b) Excavation at special locations shall employ controlled blasting technology, excavating block by block in a rational manner. Before excavation, blasting parameters satisfying design requirements shall be determined by blasting tests.
- c) For excavation of crane beams on a rock ledge, the unevenness of the excavation rock surface shall be strictly controlled. If the unevenness does not meet design requirements, necessary measures shall be employed to improve stress conditions at the joint surface.
- d) The protective layer's thickness of excavation at special locations should not be less than 2 m.
- e) For layered excavation, the distance between the bottom of crane beams on the rock ledge and the elevation of the corresponding excavation layer surface should remain greater than 2 m. The excavation shall employ the smooth blasting method.

**6.2.8** Construction of adits shall meet the following requirements:

- a) The adit settings shall be determined according to technical and economic comparisons of the underground structure layout, work quantity, master schedule, topography, geological condition, construction method, road layout, and construction machinery. Furthermore, they shall meet the following requirements:
  - 1) If the drilling and blasting excavation method is employed, the distance between two adjacent adits should be less than 3 km; the elevation difference between vertical and inclined shafts should be less than 200 m;
  - 2) If excavation from inside to outside or cavern entrance lining is needed, adits may be set up near the cavern entrance;
  - 3) For layered excavation of underground powerhouses, a permanent tunnel shall be utilized as an adit, or the adit shall be formed as a branch of the interior of the permanent tunnel. Additional ones shall be set up if necessary, or if an adit is constructed from the fork of the permanent tunnel, a construction adit should also be added if necessary.
- b) Adit layout shall meet the following requirements: geological conditions along the tunnel line

shall be favourable; the tunnel length shall be short; quantity of engineering works for the transportation route leading to the entrance of cavern branches shall be small; workload for each adit shall be roughly equivalent; a feasible waste disposal area shall exist outside the cavern; the cavern entrance elevation shall meet corresponding flood control standards.

- c) The adit section size shall meet the requirements for transportation, support, various pipeline layouts and passenger safety. If a single lane is employed, passing bays should be set up approximately every 200 m.
- d) The adit tunnel line should be orthogonal with the main tunnel, and the intersection shall meet the requirements for the minimum turning radius of the transportation route. If possible, an outward downhill slope of about 3% shall be created for the adit. The drainage ditch should be kept unblocked and a drainage well should be set up.
- e) Special drainage measures should be implemented when there is an adverse slope in the case of restricted terrain conditions.

**6.2.9** Drilling and blasting shall meet the following requirements:

- a) The excavation of the design outline of underground caverns shall employ smooth or pre-split blasting technology.
- b) Before excavation, tests shall be carried out to obtain the blasting parameters.
- c) Contractors shall design the drilling and blasting according to the design drawings, geological conditions, blasting material properties and drilling machines.
- d) Drilling and blasting work shall be carried out in accordance with the approved blasting design drawings.
- e) Drilling quality shall meet the following requirements:
  - 1) Drilling position shall be determined according to midline, waistline, and hole position outlines set out by survey;
  - 2) The adjustment range of perimeter holes in the section outline and the cutting hole position deviation should not be larger than  $\pm 50$  mm, and the deviation of other blasthole positions shall be no greater than  $\pm 100$  mm;
  - 3) The blasthole bottom shall lie on the plane required by the Blast-methodology drawings;
  - 4) All blastholes shall be set in the same direction. During drilling, they shall be regularly inspected and the drilling angle of the perimeter and pre-split blasting holes shall be properly

controlled;

- 5) Charging and blasting may not be carried out until the blastholes pass inspection.
- f) Charging, blocking, and detonation line connection for the blastholes shall be carried out according to the explosion drawings by operating personnel who have blasting certification.
- g) The main parameters of smooth and pre-split blasting shall be determined by tests, and testing parameters may be set by the engineering analogy method or by referring to Appendix D.
- h) Effect of smooth and pre-split blasting shall be inspected under the following criteria:
  - 1) Residual blasthole traces shall be evenly distributed over the excavation contour surface. The preservation rate of blasthole traces shall be no less than 80% for integrated rock, no less than 50% for relatively integrated and poorly-integrated masses, and no less than 20% for relatively fractured and fractured rock;
  - 2) The rock surface of adjacent holes shall be smooth and no blasting fissures shall exist on the hole wall;
  - 3) The step size between two adjacent blasts or the maximum external oblique value shall be less than 200 mm;
  - 4) Perforative and continuous fissures shall be formed after pre-split blasting.

**6.2.10 Mucking and transportation shall meet the following requirements:**

- a) The procedure and equipment for mucking and transportation shall be chosen according to the confirmed construction method.
- b) Stacking and utilization of stone ballast shall be considered as a whole. Not only shall engineering requirements be met to ensure engineering safety, but the requirements for environmental protection and soil and water conservation shall also be met to reduce damage to the natural environment.
- c) Mucking of medium-sized and small tunnels should employ transportation methods with tracks. If locomotive traction is employed, preference should be given to using a battery-driven locomotive.
- d) If spoil is loaded by a rock loader, the tracks shall keep up with the excavation section, and marshalling facilities shall also move forward in time.
- e) For transportation in caverns, double tracks should be used. If a single track is employed, then

lay-bys, whose effective length shall meet the train's requirements, shall be set up and their spacing shall be determined according to traffic density.

- f) If the excavation section, ventilation condition, and transportation distance so allows, mucking may employ the procedure involving dump trucks matched with loaders or excavators. The maximum longitudinal road slope shall be determined according to the transportation vehicle's performance and the working conditions of the mucking facilities, and should be 9%. The maximum length of the longitudinal slope is limited to 150 m, and the driving line of sight should be 40 m. The localized maximum longitudinal slope should be no greater than 14%.
- g) If mucking transportation employs inclined and vertical shafts, the safety coefficient of the steel wire rope for the hoisting equipment shall meet the following requirements:
  - 1) The safety coefficient of the manned elevator and hoisting basket wire shall not be less than 14.
  - 2) The safety coefficient of the wound and bound rope that straps heavy weights shall be 8.
- h) If a winch is employed in mucking transportation for inclined shafts, the following conditions shall be met:
  - 1) Measures for preventing slippage of tracks shall be put in place if the track slope is greater than  $15^{\circ}$ ;
  - 2) Sloping and flat sections of the track lane shall be connected by vertical curves, and an adverse slope shall be set up at the connection of the vertical curve and the straight section, as well as controllable vehicle stopping devices at appropriate locations;
  - 3) The hauling rope shall be in line with the centre line of the sloping section of the track, and a lower pulley support shall be put in place;
  - 4) The running speed of vehicles should not be more than 2 m/s;
  - 5) Footways and safety rails shall be set up at slope sections, and the distance between the footway edge and the vehicle outer edge shall not be less than 300 mm;
  - 6) One refuge hole should be set up about every 100 m in inclined shafts.
- i) If a chute is employed to slide slag in an inclined shaft, chute formation shall be determined according to the tilt angle of the inclined shaft, and strict safety facilities shall be employed.
- j) If the hoist bucket method is employed to transport muck in a vertical shaft, the following requirements shall be met:

- 1) If the well depth is greater than 40 m, a guiding device shall be installed for the hoist bucket.
  - 2) The weight of the hoist bucket when filled with slag shall not exceed the design value.
- k) For transportation in inclined or vertical shafts, reliable communications and signals shall be put in place to remain in contact, and signals shall be equipped with both sound and light.
  - l) Reliable brake systems and safety devices for avoiding over-rolling, over-speed, over-current and voltage drop shall be set up for the hoisting device, and the maintenance and inspection work shall be strengthened.

6.2.11 Temporary supports shall meet the following requirements:

- a) For areas that need to be supported after excavation, a temporary support scheme that mainly consists of anchor and shotcrete shall be determined according to the surrounding rock condition, cavern section pattern, section size, excavation method, and the self-stabilizing time of the surrounding rock.
- b) The shotcrete-anchorage pattern shall be determined through engineering analogy or field monitoring results, according to the surrounding rock property, section size and construction method.
- c) Truss and shotcrete-anchorage shall be employed for surrounding rock of classes IV and V, and shall be determined by implementing the design.

6.2.12 For cavern excavation in unfavourable geological conditions of sections with faults and fractures, dense bands of slightly tilting angle joints, karst development, abundant groundwater, and rock-mass expansion areas, the following requirements shall be met:

- a) For cavern excavation in unfavourable geological areas, a practical and operable construction scheme shall be formulated, and a practical and operable support scheme shall be employed. The schemes shall be reported to the supervising engineer for approval.
- b) When the tunnel body is excavated in poor geologic areas, advance exploration methods, such as excavating through a pilot tunnel on the excavation face or drilling horizontal holes along the excavation direction with large-bore horizontal drilling rigs, should be adopted to strengthen geological prediction. It is necessary to carry out proper drainage, lock the tunnel entrance, perform lining as soon as possible, adopt short footage, weak blasting, and strong support methods, perform frequent inspection, frequent observation, and frequent feedback, and implement timely reinforcement and other measures.
- c) In order to prevent instability and collapse of rocks surrounding the vault during tunnelling, the

advance support method should mainly be used in strengthening the surrounding rocks from the working face, namely, inserting the advance bolt, pipe shed, and advance grouting, and other reinforcement measures.

- d) For broken and weak-clay rocks, rocks surrounding the main tunnel can be strengthened through the adit and then the main tunnel can be excavated. The scope of reinforcement depends on geological engineering conditions. Reinforcement measures can be implemented using bolts, slab, or bored piles and shall be determined according to specific engineering conditions.
- e) According to engineering geology and hydrogeology situations in the unfavourable geologic region, grouting may be used to reinforce the surrounding rocks, stop water, or for the purpose of both stopping water & reinforcement.
- f) If the rock surrounding the cavern is divided into unstable blocks by a combination of unfavourable discontinuities, the construction method of simultaneously excavating and anchoring shall be employed.
- g) In areas with abundant groundwater, the rules governing the underground activity, inflow yield, groundwater table and groundwater supply sources shall be ascertained, and technical measures such as drainage, plugging, interception and diversion may be employed according to the actual situation.
- h) During the excavation in karst areas, the karst types, corrosion patterns, filling and accumulation properties, distribution, and groundwater conditions should be previously ascertained. The excavation methods and treatment measures should be determined according to the scale and stability of the karst. The cave's stability should not be destroyed. Plugging, isolation, removal, or supporting methods should be used to deal with unstable rocks in karst caves. For leaking channels, weak water-permeable materials or cement grouting can be used if necessary.
- i) For cavern excavation and support of a cavern section in unfavourable geological conditions, the density of monitoring sections shall be increased. Observation frequency shall be increased and observation results shall be reported in time. If any abnormal condition occurs, strengthening measures shall be employed at once.
- j) After the collapse occurs, the cause of the collapse and its scale and law should be ascertained, and measures should be put forward to reasonably deal with it so as to prevent the extension and expansion of the scope of the collapse. For small landslides caused by crack expansion, the shotcrete method, beam-lifting method, and substitution support method should be adopted; for narrow and long landslides, the roof-supporting method and beam-lifting method should be adopted; for medium landslides, the shotcrete-anchoring method, reinforcement-bent method, roof-protection method, and steel pipe-roof-framing method should be used; for large landslides, the grouting method, annular pilot-tunnelling method, and concrete longitudinal beam method should be used; water control should be performed before collapse prevention when



groundwater conditions are intense.

6.2.13 The safety items to be monitored during cavern excavation and their quantities shall be determined according to the actual conditions of engineering topography, geomorphology, surrounding rock condition, and construction method, and the monitoring equipment shall also be selected accordingly. Collection, organization, and analysis of safety monitoring data shall be properly implemented. If abnormal deformation happens, treatment measures shall be employed in good time.

6.2.14 For underground cavern construction, the ventilation and dust and harmful gas prevention work shall be properly performed.

6.2.15 During the excavation of underground caverns, the oxygen volume in the cave shall be no less than 20% , and the harmful gas and dust content shall comply with the health regulations.

6.2.16 Ventilation mode shall be comprehensively determined according to the layout of underground cavern, cavern scale and size, construction procedure, construction method, working face harmful gas and dust content and hazard degree and other factors.

### 6.3 Foundation treatment

6.3.1 Clearing and treatment of the foundation surface shall meet the following requirements:

- a) If the foundation is excavated to the base surface, the surface shall be cleared up and properly treated.
- b) When clearing the soft soil foundation of structures, matter on the ground such as grass, bamboo, trees, roots, riprap, sludge, humus, peat, tombs and all kinds of buildings, shall be totally cleared up. Sloping residual deposits and landslide mass shall be cleared up as per the design requirements.
- c) Treatment of under break of the rock foundation surface shall meet the requirements of 6.1.3.
- d) If the foundation surface tilts along the direction of flow, it shall only slightly tilt upstream and the gradient should be no greater than 1 : 10. If there is a reverse slope under the foundation of the bank slope, it shall be changed to a positive slope. Sharp angles shall be changed to obtuse angles. For other situations, the structural measures such as filling up and making them even with grouted rubble or concrete, shall be implemented to meet the requirements hereinabove.
- e) After excavation, the foundation surface should meet the design requirements. There are no loose rocks and broken rocks, and the surface is clean and free from dirt or oil pollution.
- f) Drill holes, adits, shafts, trial trenches that are left over from geological exploration and testing shall be backfilled and disposed of according to the design requirements.

- g) Serious geological problems such as cracks, faults, karst caves, grottos and weak intercalations, which are exposed by excavation, shall be disposed of on time according to the design requirements. If there are no design requirements, it is recommended to refer to the following measures:
- 1) For common joints and fissures, the mortar or concrete spouting method can be used to seal up the fissures. For wide fissures, cement mortar or concrete shall be backfilled into the fissures after the filling substance has been cleared to a certain depth.
  - 2) For fault-fracture zones, depending on actual circumstances, when the fractures have been excavated to a certain depth, concrete panels or concrete plugs should first be poured, or the faults plugged with cement-stone masonry, and then consolidation grouting should be carried out.
  - 3) For karst caves and grottos, it is recommended to plug caves with concrete plugs and then grout the cave for filling and consolidation.
  - 4) For weak intercalations, shallow ones shall be totally removed, while deep ones shall be removed to a certain depth and then sealed up by backfilling concrete.
- h) Gushing or seepage water on the foundation surface shall be properly plugged and drained away. Neither the quality of clearing the foundation, backfilling or pouring nor the geological conditions of the foundation shall be worsened because of foundation seepage.
- i) When there is no construction work proceeding on upper structures, weak foundation surfaces that are easily weathered, softened and cracked by freezing shall be sealed up on time by mortar or concrete, or be treated according to the design requirements.
- j) When the foundation treatment has been completed, it shall be inspected and accepted in time. When the foundation treatment has been accepted to be qualified, contractors or surveyors shall make a final foundation geological map. Contractors shall not move on to the next steps such as backfilling or pouring until the foundation treatment has been accepted.

**6.3.2** Soft soil foundation treatment includes replacement, reinforcement, preloading, compaction and bored pile, precast pile and other methods.

**6.3.3** Pre-stressed anchorage is mainly used for building foundation anchorage, retaining wall anchorage, high slope mountain anchorage, and underground cavern rock anchorage.

## **6.4 Anti-seepage treatment**

**6.4.1** The scope of seepage control includes dam body, dam foundation, and abutment. Casing shaft, clay (cement clay slurry), and splitting grouting should be adopted for seepage control of

earth-rock fill dam body, and curtain grouting and a cut-off wall should be adopted for seepage control at dam foundation and abutment.

6.4.2 Anti-seepage treatment of the earth-rock fill dam casing well shall meet the following requirements:

- a) Review of the borrow area for anti-seepage relief wells of earth-rock fill dams shall meet the following requirements:
  - 1) Contractors shall review the soil borrow area before the construction of relief wells. The contents of the review include the quality and amount of soil reserves.
  - 2) Soil quality indices, which should include the soil type, block size, clay content, water content, permeability coefficients, maximum dry density and so on, shall meet the design requirements.
  - 3) Soil reserves shall be basically the same as the data in the Geological Exploration Report, and shall also be no less than 2.5 times the design backfill quantity.
- b) Excavation of relief wells shall meet the following requirements:
  - 1) Set out the construction drawings to determine the excavation axis of the relief wells. The centre line of the relief wells should lie in the original anti-seepage body slightly upstream of the dam axis. The centre line can be slightly adjusted if the geological condition is poor, but the thickness of the lap joints shall not be reduced. Fixed foundation piles shall be set up at the two ends of the extended axis of the relief wells. The positions of the relief wells' centre points shall be rechecked before excavating.
  - 2) Equipment used in excavation of overlapped wells shall meet the design requirements for bore diameter and perpendicularity.
  - 3) Casing shaft must be constructed in strict sequence from the main shaft to the auxiliary shaft.
  - 4) The excavation depth of relief wells or the geological conditions at the bottom of the wells shall meet the design requirements.
- c) Before backfilling the relief wells, there shall be no sundry matter or water logging in the bottom of the wells. When the relief wells have been excavated, the acceptance of the concealed works shall be properly recorded on time, including the hole number, time, bottom elevation, hole deviation rate, overlapping thickness, geological conditions at the bottom, and the exceptional situation of hole drilling. The relief wells shall be backfilled according to construction parameters determined by testing.

- d) The treatment of seepage and collapse in the wells shall meet the following requirements:
- 1) If there is any seepage, backfill the hole with clay first, and then tamp the backfilled soil to strengthen the hole wall; finally, re-excavate the wells. For the permeable foundation, the cement soil in the range of 1 : 4 to 1 : 5 should be backfilled for 1 m for the bottom of the shaft.
  - 2) If parts of the wells have collapsed, sleeves can be put into the wells to support the boreholes.
  - 3) Auxiliary shafts can be drilled upstream to reinforce the collapsed wells. Drain off water logging in the shafts, and then excavate along the axis section of the relief wells.
  - 4) A design modification notice shall be issued by the design organization for any adjustment of the axis of relief wells due to special geological reasons.
- e) Backfilling of the relief wells shall meet the following requirements:
- 1) The backfilled soil shall meet design requirements and relevant documents.
  - 2) Tamping tests shall be thoroughly performed before backfilling the relief wells. Construction parameters such as the thickness of the soil layer, the weight and height of drop of the hammer, and the tamping times shall be determined according to the test results. When the backfill is within 2 m of the dam crest, the pounder height should be less than 2 m.
  - 3) When the construction of the relief wells has been completed, a layer of soil with a thickness of 200 mm to 300 mm shall be removed from the top of the relief wells, and then backfilling with a protective layer of sandy loam shall be carried out.
- f) The construction quality of relief wells shall meet the following requirements:
- 1) Soil sample tests of the backfill soil should be done, including particle analysis, maximum dry density, optimum water content, and permeability coefficient. The clay content of the backfill soil should range from 15% to 50%. The plasticity index shall be no greater than 20. The permeability coefficient should be no greater than  $1 \times 10^{-4}$  mm/s. The water content of the backfill soil should be around the optimum water content, and the deviation should be no greater than  $\pm 2\%$  to  $\pm 3\%$ . The soil should appear to be loose and without caking.
  - 2) The deviation of the centre points of excavating wells shall be no greater than  $\pm 30$  mm, and the deviation rate of boreholes shall be no greater than 0.4%. The elevation of the hole bottom shall meet design requirements, and it should reach the bottom limit of strongly weathered layers or relatively impermeable layers.

- 3) The degree of compaction of backfill soil should be no less than 96% , and the compaction degree of unqualified backfill soil shall be no less than 98% of design value. Furthermore, the distribution of unqualified samples shall not be concentrated.
  - 4) The dry density (compaction) of the backfilled soil shall be measured at the bottom, middle and top of every casing shaft. Every 10 holes should be taken as a unit , and a group of tests for the permeability coefficient of the compacted soil should be performed.
- g) The construction safety of relief wells shall meet the following requirements:
- 1) The construction safety of relief wells mainly includes personnel safety, equipment safety and electrical safety. The equipment operators shall be trained and certified. The construction equipment shall be reliable. The wirerope shall be undamaged and flawless, and the rotating parts shall have protection devices.
  - 2) Unrelated persons shall not be on the construction site when the relief wells are being constructed. During construction rest times, the openings of the relief wells shall be covered, and warning boards shall be set up around the openings.
  - 3) Special equipment shall be used in sampling the backfill soil of relief wells.

**6.4.3** The curtain grouting of dam foundations shall meet the following requirements:

- a) Grouting materials and slurry:
- 1) The type of cement used in the grouting project shall be determined by design according to the grouting purpose and the erosion effect of environmental water.
  - 2) The cement used for grouting must meet the quality standard, and damp and agglomerated cement shall not be used. The grouting water shall meet the requirements for mixing hydraulic concrete.
  - 3) The cement grouting of hydraulic structures generally uses pure cement slurry. In special geological condition or by special requirement, this shall be demonstrated by on-site grouting testing.
  - 4) According to grouting needs, the cement slurry can be mixed with the following admixture:
    - Sand: it shall be hard natural sand or artificial sand, the particle size shall be no greater than 2.5 mm, the fineness modulus shall be no greater than 2.0, the SO<sub>3</sub> content shall be less than 1% , the mud content shall be no greater than 3% , and the organic matter content shall be no greater than 3%.

- Cohesive soil: plasticity index shall be no less than 14, clay (size is less than 0.005 mm) content shall be no less than 25%, sand content shall be no greater than 5%, organic matter content shall be no greater than 3% ;
  - Fly ash: shall be selected fly ash, it shall be no thicker than the cement used at the same time, the loss of ignition shall be less than 8%, SO<sub>3</sub> content shall be less than 3% ;
  - Water glass: the modulus shall be 2.4 to 3.0, the concentration shall be 30 to 45 Baume Degree;
  - Other admixture.
- 5) According to the grouting needs, admixtures such as an accelerator, water reducing agent and stabilizer can be added to the cement slurry.
- 6) The types and amounts of all kinds of admixtures and additives shall be determined through laboratory grouting testing and field grouting testing.
- b) Slurrying
- 1) Slurrying materials must be weighed, and the weighing error shall be less than 5%. Cement and other solid-phase materials shall use weighing method.
- 2) All kinds of slurries must be stirred evenly and the slurry density must be measured.
- 3) The mixing time of pure cement slurry shall be no less than 3 min when using an ordinary mixer, and no less than 30 s when using a high speed mixer. The slurry shall be sieved before use, and the time from preparation to use shall be less than 4 hrs.
- 4) Mixing fine cement slurry and stabilizing slurry shall be added with water reducing agent and adopt high speed mixer. The speed of the high speed mixer shall be greater than 1 200 rpm. The stirring time shall be determined by testing. The time from preparation to use of the fine cement slurry shall be less than 2 hrs.
- 5) Pure cement slurry with water cement ratio of 0.5 : 1 shall be prepared in a centralized slurrying station. The slurry flow rate shall be 1.4 m/s to 2.0 m/s. Grouting density shall be measured and mixed at each grouting site.
- 6) In the cold season, the machine room and grouting pipeline shall be well-protected in order to prevent cold and keep warm. During the hot season, measures for preventing heat and sunshine shall be implemented. The slurry temperature shall be maintained between 5 °C to 40 °C. If slurrying is done with hot water, the water temperature shall not exceed 40 °C.

## c) Grouting equipment and tools

- 1) The speed and mixing capacity of the mixer shall correspond to the type of mixing slurry and the discharge volume of the grouting pump respectively, and shall ensure the uniform and continuous mixing of the slurry.
- 2) The grouting pump's performance shall be in accordance with the type and concentration of grout. The allowable working pressure shall be 1.5 times of the maximum grouting pressure, and it shall have sufficient discharge and stable working performance. Multi-cylinder plunger grouting pumps shall be used for grouting pure cement slurry.
- 3) The grouting pipeline shall ensure the smooth flow of grout and be able to withstand the maximum grouting pressure of 1.5 times.
- 4) The pressure gauges shall be installed at both the grouting pump and the grouting hole. The pressure shall be between 1/4 and 3/4 of the maximum value of the pressure gauge. Pressure gauges shall be checked frequently, and unqualified and damaged pressure gauges are strictly prohibited. There shall be a slurry separation device between the pressure gauge and the pipeline.
- 5) The grouting plug shall be compatible with the grouting method, grouting pressure and geological conditions. The rubber plug (ball) shall have good expansion and pressure resistance, reliably close the grouting hole section under the maximum grouting pressure, and be easy to install and remove.
- 6) When the grouting pressure is greater than 3 MPa, the following grouting equipment and tools shall be prepared and used: high pressure grouting pump, the pressure oscillating range is not more than 20% of the grouting pressure; corrosion-resistant grouting valve; wire braided rubber hose; large-range pressure gauge, the maximum value shall be 2.0 to 2.5 times the maximum grouting pressure; the orifice sealer or special high pressure grouting plug.

## d) General provisions for grouting

- 1) Before the impoundment, the curtain grouting and its quality inspection and acceptance work below the minimum reservoir water level at the initial stage of impoundment shall be completed. After impounding, the curtain grouting shall be constructed when the reservoir water level is lower than the elevation of the orifice.
- 2) The bedrock grouting in the same section must be carried out following the sequence of consolidation grouting followed by curtain grouting.
- 3) Curtain grouting must be carried out according to the principle of increasing compactness in

sequence. For curtains composed of three rows of holes, the grouting of the side holes shall be carried out first, and then the grouting of the middle holes shall be carried out; the side holes shall be divided into three-sequences construction, and the middle holes can be divided into two-sequences or three-sequences construction. For curtains composed of two rows of holes, it is advisable to grout the downstream holes first and then grout the upstream holes; each row of holes shall be divided into three-sequences construction. Single-row curtain grouting holes shall be divided into three-sequences construction.

- 4) When the curtain grouting adopts the top-down sectional grouting method, in a dam section or a unit project, the first sequence holes in the back sequence row shall be drilled after the last sequence holes in the front sequence row have been filled for 15 m in the rock.

The height difference of the hole grouting in the rock between two sequence holes adjacent to each other on the same row, and between the first sequence holes on the back sequence row and the last sequence holes on the corresponding front sequence row shall not be less than 15 m.

- 5) The main drainage hole and the lifting pressure observation hole behind curtain must pass the curtain grouting inspection on the corresponding part before drilling.
- 6) Grouting tests that may cause adverse consequences shall not be carried out on the curtain line during construction.

e) Drilling

- 1) Curtain grouting holes shall be drilled with a rotary drill and diamond bit or carbide drill.
- 2) The deviation between the position of drilling holes and the design position of curtain grouting shall be no greater than 100 mm. Design permission shall be obtained when changing the hole position for any reason. The actual hole position shall be recorded; the hole depth shall meet the design requirements.
- 3) The smaller diameter of the curtain grouting hole shall be used, and the wall of the drilling hole shall be straight and complete.
- 4) Curtain grouting hole must ensure accurate orientation. The rig installation must be straight and stable; the holes shall be buried with orifice pipe; the vertical axis of the rig and the orifice pipe shall be consistent with the designed hole direction; the drilling shall use the long and thick diameter drill and properly control the drilling pressure.
- 5) The hole inclination of the curtain grouting hole shall be measured. If the deviation exceeds the requirements, it shall be quickly corrected or the remedial measures shall be taken.



- 6) For curtain grouting holes with a vertical or apex angle less than  $5^{\circ}$ , the deviation of the bottom of the hole shall not exceed 0.25 m (hole depth 20 m), 0.50 m (hole depth 30 m), 0.80 m (hole depth 40 m).
  - 7) For the inclined hole with an apex angle greater than  $5^{\circ}$ , the maximum allowable deviation value of the bottom of the hole can be appropriately relaxed according to the actual situation, and the azimuth deviation value shall not be greater than  $5^{\circ}$ .
  - 8) When drilling grouting holes, the rock formation, lithology and various conditions in the holes shall be recorded in detail.
  - 9) When it is difficult to drill in the case of caves, collapsed holes or falling rocks, it can be grouted first and then drilled. If it is found that there is concentrated water leakage, the location of water leakage, the amount of water leakage and the cause of water leakage shall be identified. After treatment, drilling shall be carried out again.
- f) Drilling flushing, crack flushing and water pressure testing
- 1) Grouting holes (sections) shall be drilling flushing before grouting, and the deposit thickness of the holes shall not exceed 200 mm.
  - 2) The crack in curtain grouting holes (sections) shall be flushed with pressure water before grouting until the return water is clean. The flushing pressure may be 80% of the grouting pressure, and if the value is greater than 1 MPa, 1 MPa shall be adopted.
  - 3) In areas with complex geological conditions such as karst, faults and large fissures, the question of whether the curtain grouting holes (segments) need to be flushed and how they should be flushed shall be determined by on-site grouting testing or design.
  - 4) When the curtain grouting adopts the top-down section method, the pilot hole shall be subjected to the water pressure test from the top to the bottom, and the grouting section of each sequential grouting hole shall be subjected to simple water pressure before grouting.
  - 5) When the curtain grouting adopts the bottom-up section grouting method, the pilot hole shall still be subjected to the water pressure test from the top to the bottom. Each sequence of grouting holes shall be subjected to drilling flushing and crack flushing before the grouting. Except for the bottom section of the hole, each grouting section may not be subjected to crack washing and simple water pressure before grouting.
- g) Grouting method and grouting style
- 1) When the length of the bedrock of the grouting hole is less than 6 m, the full-hole one-time grouting method can be adopted; when it is greater than 6 m, the top-down section grou-

ting method, the bottom-up section grouting method, the comprehensive grouting method or hole closure grouting method can be used.

- 2) The circular grouting method shall be preferred for curtain grouting, and the distance between the grouting pipe and the bottom of the hole shall not be more than 500 mm.
  - 3) The length of the curtain grouting section shall be 5 m to 6 m, which can be properly reduced or increased under special circumstances, but no greater than 10 m.
  - 4) When curtain grouting is carried out, the contact section of the concrete and bedrock of the dam shall be separately grouted firstly and shall be solidified, and the length of the contact section in the rock shall not exceed 2 m.
  - 5) When using the top-down section grouting method: the grouting plug shall be plugged 0.5 m above the bottom of the grouted section to prevent grouting leakage; In the section without water gushing at the orifice, no solidification is required after grouting. However, in complex areas with complex geological conditions such as faults and fracture zones, solidification is preferable. The solidification time shall be determined according to geological conditions and engineering requirements.
  - 6) If the length of the grouting section exceeds 10 m, remedial measures shall be taken when the bottom-up section grouting method is adopted.
- h) Grouting pressure and slurry transformation
- 1) Grouting pressure shall be determined by grouting testing, or can be calculated by formula or according to experience, and then adjusted during grouting construction.
  - 2) When circular grouting is adopted, the pressure gauge shall be installed on the orifice returning pipeline; when pure pressure grouting is adopted, the pressure gauge shall be installed on the inlet pipe of the orifice. The pressure reading shall be the median value of the pressure gauge pointer swing value. When the grouting pressure is 5 MPa or more, the peak value can also be read. The swinging range of the gauge pointer shall be less than 20% of the grouting pressure, and the swing amplitude shall be recorded.
  - 3) Grouting shall reach the design pressure as soon as possible, but when the injection rate is high, it shall be graded to increase pressure.
  - 4) The concentration of slurry shall be from thin to thick and change step by step. The water-cement ratio of the curtain grouting slurry can adopt seven ratios of 5 : 1, 3 : 1, 2 : 1, 1 : 1, 0.8 : 1, 0.6 : 1, 0.5 : 1. The water-cement ratio of beginning grouting can be 5 : 1.
  - 5) Curtain grouting slurry transformation: When the grouting pressure remains unchanged, the

injection rate continues to decrease, or when the injection rate is constant and the pressure continues to rise, the water-cement ratio must not be changed; when the injection amount of a certain grade slurry has reached above 300 L or injection time has reached 1hr, and the grouting pressure and injection rate are unchanged or the change is not significant, it should be changed to a more thicker level; when the injection rate is greater than 30 L/min, it can be thickened according to the specific situation.

i) Grouting end standard and sealing method

- 1) When the curtain grouting adopts the top-down section grouting method, under the specified pressure, when the injection rate is not more than 0.4 L/min, the grouting can be continued for 60 min; or when it is not more than 1 L/min, the grouting can be continued for 90 min, and the grouting can be completed; when using the bottom-up section grouting method, the time of continuous grouting can be correspondingly reduced to 30 min and 60 min, and the grouting can be completed.
- 2) When the curtain grouting adopts the top-down section grouting method, the grouting hole shall be sealed by “segment pressure grouting sealing method”; when bottom-up section grouting is adopted, the “replacement and pressure grouting sealing method” or “pressure grouting sealing method” shall be adopted.

j) Special case handling

- 1) During the grouting process, the slurry overflow and slurry leakage shall be treated by the methods, such as caulking, surface sealing, low pressure, thick slurry, current limiting, amount limiting, intermittent grouting according to the specific conditions, .
- 2) When the slurry is mixed during the curtain grouting process, if the slurry mixing hole has grouting conditions, grouting can be carried out at the same time, and one hole shall be grouted by one pump. Otherwise, the slurry mixing hole shall be plugged. After the grouting is finished, the slurry hole shall be swept, flushed, and then drilled and grouted.
- 3) The grouting work must be carried out continuously. If it is interrupted for any reason, it can be treated according to the following principles: the grouting shall be resumed as soon as possible. Otherwise, the drilling hole shall be flushed immediately, and then grouting shall be resumed. If it cannot be flushed or the flushing is invalid, the hole shall be swept, and then grouting is resumed; when grouting is resumed, the grouting shall be carried out with the cement slurry of beginning grouting. If the injection rate is similar to that before the interruption, the grout can be replaced with the cement slurry before the interruption. If the injection rate decreases more than before interruption, the slurry shall be thickened step by step, and then continue to be injected. After resumption of grouting, if the injection rate is much lower than before the interruption, and the suction is stopped within a short time, remedial measures shall be taken.

- 4) For the grouting hole section with water gushing at the orifice, the water gushing pressure and water gushing amount shall be measured and recorded before grouting. According to the water gushing situation, the following measures can be adopted for comprehensive treatment: top-down section grouting; increase section length; high grouting pressure; end of thick slurry; screen slurry; close slurry; pure pressure grouting; rapid solidification of slurry; to be solidified; pressure grouting and seal the hole.
  - 5) When the grouting section is injected in a large amount and the grouting is difficult to end, the following measures can be used: low pressure, thick slurry, current limiting, amount limiting, intermittent grouting; add accelerated coagulant in the slurry; inject stable slurry or mixed slurry. After the section has been treated, the hole shall still be swept, and the grouting shall be carried out according to the technical requirements until the end.
  - 6) If the return slurry becomes thicker during the grouting process, the new slurry with the same water-cement ratio shall be replaced for grouting. If the effect is not obvious, the grouting can be stopped after 30 min of continuous grouting.
- k) Engineering quality inspection
- 1) Curtain grouting quality inspection shall be based on the test results for water pressure at the hole, combined with the analysis of the completion data and test results, and perform a comprehensive evaluation.
  - 2) The curtain grouting inspection hole shall be arranged in the following parts:
    - the centre line of the curtain;
    - the parts with complicated geological conditions such as rock fracture, fault and macropore;
    - near the hole with large injection volume;
    - the parts with excessive deviation of drilling hole, abnormal grouting conditions and the parts with influence on the quality of curtain grouting according to the analysis data.
  - 3) The number of curtain grouting inspection holes shall be 10% of the total number of grouting holes. At least one inspection hole shall be placed within a dam section or a unit project.
  - 4) Curtain grouting inspection hole water pressure testing shall be carried out 14 days after the end of grouting at this part.
  - 5) The curtain grouting inspection hole shall be subjected to the water pressure test from the

top-down with section plugging. The test adopts the five-point method or the single point method.

- 6) The curtain grouting inspection hole shall adopt the core, calculate the acquisition rate and describe it.
- 7) Curtain grouting quality water pressure testing, the qualification rate of the dam concrete and bedrock contact section and the next section shall be 100%; the qualified rate of the following sections shall be above 90%, the permeability value of the unqualified section shall not exceed 100% of the design stipulated value, which is not concentrated, and the grouting quality can be considered qualified.
- 8) The quality of the sealing hole of the curtain grouting hole shall be sampled.

## 6.5 Concrete works

### 6.5.1 Formwork

#### 6.5.1.1 Selection of the formwork type shall meet the following requirements:

- a) The type of formwork shall be compatible with the characteristics of the structures and the construction method.
- b) For mass concrete with simple structure, such as gravity dams and arch gravity dams, large combination formwork, especially cantilever type formwork, should be adopted. For board-type, beam-type and column-type structures, combination formwork should be adopted.
- c) For structures with curved sections whose surfaces must be smooth, such as piers, thin arch dams, surfaces of spillover dams and pit shafts, sliding steel formwork should be selected as first choice.
- d) For long structures with the same sections, such as tunnels and crowns of powerhouses, mobile formwork should be adopted, such as steel form carriers.
- e) For non-standard structures, such as warped surfaces of water intakes, volutes and elbow bends, wood formwork can be used when combined steel formwork cannot be adopted for these structures.
- f) Precast reinforced concrete formwork can be adopted in parts with special demands such as the anti-scouring parts of flow-passing surfaces of piers, parts with aesthetic requirements and the load bearing parts of galleries in the dam body.
- g) In some parts with appropriate conditions, soil can be used to build arch rings or cover plates.

The degree of compaction of the filling soil shall be greater than 90%. There shall be a protective layer on the soil surface, and the layer shall be easy to peel off from the mould and have sufficient strength and smoothness. Measures shall be taken to protect the soil from water erosion.

6.5.1.2 Formwork and supports shall meet the following requirements:

- a) They shall have sufficient strength, stiffness and stability.
- b) Make sure the shape, size and relative position of the structures meet the design requirements when the concrete has been grouted in. Any errors shall be within the allowable limits.
- c) The formwork surface shall be clean and smooth, and the seams shall be closely jointed.
- d) Formwork shall be economical, durable and be easy to make, install and dismantle. Try to serialize and standardize the manufacture of the formwork.
- e) Steel, especially carbon structural steel, wood, and other new materials should be used for making formwork and supports. As little wood as possible should be used. Carbon structural steel can be used for steel material. The grade of wood should not be less than III. Decayed, seriously twisted or brushy wood shall not be used to make formwork.

6.5.1.3 The design of the formwork and supports shall meet the following requirements:

- a) The formwork for important structures and some special kinds of formwork, such as load bearing, mobile, slide and permanent formwork, shall be specially designed, and the requirements for the material, manufacture, installation, usage and the dismantling process shall be stated as well.
- b) The following loads shall be taken into consideration for the design of formwork and supports. For calculation of the loads see Appendix E.
  - 1) Deadweight of formwork and supports;
  - 2) Weight of steel bars and embedded parts;
  - 3) Weight of fresh concrete;
  - 4) Loads of people, pouring equipment and transport machines;
  - 5) Dynamic loads of vibrating concrete;
  - 6) Lateral pressure from fresh concrete on the formwork;

- 7) Uplift pressure from fresh concrete on the formwork;
- 8) Dynamic loads of pouring concrete;
- 9) Wind loads;
- 10) Other loads.
- c) In calculating the strength and stiffness of formwork and supports, the worst case load combination in Table 16 should be chosen according to the type of formwork used.

Table 16 Frequently-used load combinations for formwork

No.	Type of formwork	Load combination (The numbers refer to those in 6.5.1.3 (b) )	
		Calculation of strength	Calculation of stiffness
1	Underside formwork of board and shell	1) + 2) + 3) + 4)	1) + 2) + 3) + 4)
2	Underside formwork of thick board, beam and arch	1) + 2) + 3) + 4) + 5)	1) + 2) + 3) + 4) + 5)
3	Lateral vertical formwork of beam, arch, column (side length $\leq 300$ mm), wall (thickness $\leq 400$ mm)	5) + 6)	6)
4	Lateral vertical formwork for large size structures, thick board, column (side length $> 300$ mm), wall (thickness $> 400$ mm)	6) + 8)	6) + 8)
5	Cantilever formwork	1) + 2) + 3) + 4) + 5) + 8)	1) + 2) + 3) + 4) + 5) + 8)
6	Tunnel lining formwork trolley	1) + 2) + 3) + 4) + 5) + 6) + 7)	1) + 2) + 3) + 4) + 5) + 7)
<b>NOTE</b> Load 8) shall be considered when the dynamic load of pouring concrete has a large influence on the bearing capacity and deformation of the formwork.			

- d) When checking the stability of resistance to overturning of the load-bearing formwork and supports, the upsetting moment, stabilizing moment and the coefficient of stability of resistance to overturning shall be checked. Wind loads, actual possible maximum horizontal forces and upsetting moments caused by 1.5 kN/m horizontal forces acting on the edge of the load bearing formwork shall be respectively calculated to decide the maximum value among them. When calculating the stabilizing moment, the deadweight of formwork and supports shall be multiplied by 0.8, the weight of steel bars shall be included if steel bars have been installed. The coefficient of stability of resistance to overturning shall be greater than 1.4.
- e) When checking the stiffness of formwork and supports, the distortion shall not be greater than the following values:

- 1) For formwork of exposed surfaces of structures, the maximum distortion is 1/400 of the span of formwork members.
- 2) For formwork of concealed surfaces of structures, the maximum distortion is 1/250 of the span of formwork members.
- 3) Compressive distortion and elastic deflection of the supports shall be no greater than 1/1 000 of the calculated span of structures.

6.5.1.4 The allowable error in formwork manufacture shall comply with the requirements of formwork design, and should be no greater than the values required in Table 17.

**Table 17 Allowable error of formwork manufacture**

Unit: mm

No.	Items	Allowable error
1	Wood formwork	
	1) Length and width of formwork;	± 3
	2) Elevation difference between surfaces of two adjacent boards;	1
	3) Unevenness of formwork (checked by 2 m rulers);	5
	4) Width of gaps between boards	1
2	Steel formwork	
	1) Length and width of formwork;	± 2
	2) Unevenness of formwork (checked by 2 m rulers);	2
	3) Position of holes of connection fittings	± 1
<p><b>NOTE</b> Allowable error of some special formwork, such as heteromorphic formwork (volutes, draft tubes), slide, mobile formwork and permanent formwork, shall comply with the design requirements.</p>		

6.5.1.5 Installation of formwork shall meet the following requirements:

- a) Formwork shall be installed according to what is set out in the design drawings; more control points should be set up for important structures.
- b) Formwork supports shall be based on solid foundations or old concrete and with enough bearing area. Measures shall be taken to prevent any sliding movement of diagonal bracings. Waterproofing measures shall be taken in collapsible loess areas. Anti-freezing and thawing measures shall be taken in areas that have soil with frost-induced expansion.
- c) There shall be enough bars fixed firmly between the stand columns of supports and scaffolds.
- d) The steel braces of formwork shall not be bent, and the diameter should be greater than 8 mm. The braces shall be fixed firmly to the anchor rings. Anchoring parts, such as bolts and steel bar rings shall be of sufficient strength when bearing loads.



- e) The pillars of multi-layer supports shall be vertical, pillars on different layers shall be in the same centre line, the cross sole timber of supports shall be even, and effective structural measures shall be implemented to ensure stability.
- f) If the span of a cast-in-place reinforced concrete beam or board is no less than 4 m, the formwork shall have arch cambers. If there is no specific design stipulation, the height of the arch camber should be 2/1 000 to 3/1 000 of the span length.
- g) The formwork joints shall be tight and without leakage. A release agent shall be spread on the surface between the formwork and the concrete. Mud, cement and oil stains on reusable formwork shall be cleaned.
- h) When pouring, the formwork shall be inspected by specific watch keepers at any time. If there is any problem such as distortion or leakage, measures shall be taken in good time.
- i) The allowable error for formwork installation shall meet the requirements of Table 18 if no requirements are given in the design documents.

Table 18 Allowable error for formwork installation

Unit: mm

No.	Items		Exterior surface	Interior surface
1	Evenness of formwork	Elevation difference between surfaces of two adjacent boards	2	5
		Evenness of surface (checking by 2 m rulers)	5	10
2	Mass concrete structures	Error between actual and design boundary line	10	15
		Internal size of horizontal section	± 20	
3	Non-mass concrete structures	Position of axis		5
		Internal size of section	Foundation	± 10
			Pier, wall, column, beam	± 5
		Vertical deviation	Height ≤ 5 m	6
Height > 5 m	8			
4	Surface elevation of underside formwork for load bearing		± 5	
5	Size and position of preformed holes		10	

6.5.1.6 The removal time of cast-in-place concrete formwork shall meet the design requirements. If there is no design stipulation, it shall meet the following requirements:

- a) Lateral formwork of non-load bearing structures shall not be removed until the concrete strength has become greater than 2.5 MPa or the surface and edges will not be damaged during the removal process.

- b) For load-bearing formwork and supports, the concrete strength shall meet the requirements of Table 19.
- c) The removal time for some parts that need to be temperature-controlled to prevent cracks shall be especially decided.

**Table 19 Required concrete strength of cast-in-place structures for removing formwork**

Type of structure	Span of structure (m)	Percentage of the standard value of the design concrete strength (%)
Board	≤2	50
	>2, ≤8	75
	>8	100
Beam, arch, shell	≤8	75
	>8	100
Cantilever component	≤2	75
	>2	100
<p><b>NOTE</b> The standard value of the design concrete strength means the compressive strength of the concrete corresponding to the design concrete grade.</p>		

### 6.5.2 Steel bars

#### 6.5.2.1 Steel bars shall meet the following requirements:

- a) Grades and specifications for steel bars used in reinforced concrete structures shall comply with the requirements of the design documents and the quality of hot-rolled steel bars shall comply with the requirements.
- b) Steel bars shall have ex-factory quality assurance certificates; before the bars are used, yield strength, tensile strength, post-fracture elongation, and cold bending tests shall be conducted in accordance with the regulations. For steel bars with “E” added in the grades, the maximum total elongation test item should be added, and the ratio of the measured tensile strength to the measured yield strength should not be less than 1.25; the ratio of the measured yield strength to the characteristic value of the yield strength should not be more than 1.30; and the maximum total elongation should not be less than 9%. Welded joints for steel bars that are to be welded should be inspected by sampling. Steel bars with unknown grades or abnormal properties found in use shall not be used until re-inspected as being qualified, but shall not be used in important parts of load-bearing structures.
- c) Replacement of steel bars shall meet the requirements of current design specifications for reinforced concrete hydraulic structures, and shall be agreed upon by the design organization.

6.5.2.2 Processing of steel bars shall meet the following requirements:

- a) The surface of the steel bars shall be clean. Oil stains and scraps on the surface shall be removed before processing the steel bars. Steel bars shall be straight and without partial bends. Scars on steel bars after processing shall not reduce the sectional area of a steel bar by more than 5%; the bending angle, radius and shape of the steel bars shall meet the requirements of design drawings. If there is no design stipulation, all ends of tensile plain round steel bars shall be bent to semi-circular hooks, whose inner diameter shall be no less than 2.5 times the steel bar's diameter, and whose straight parts should not be shorter than 3 times the steel bar's diameter.
- b) The allowable error in processing steel bars shall meet the requirements of Table 20.

**Table 20 Allowable error in processing steel bars**

Unit: mm

No.	Items	Allowable error
1	The total length of load-carrying bars along the length direction	$\pm 10$
2	The starting position of hooks at the ends of bars	$\pm 20$
3	The length of each part of the stirrup	$\pm 5$

6.5.2.3 The joints of steel bars shall meet the following requirements:

- a) When there are special design requirements, the joints of steel bars shall be constructed according to the design requirements. The longitudinal stressed steel bars should be set at the place where members are less stressed and staggered. The connection mode for the steel bar joint is selected according to the material properties of the steel bar, and welded joints or mechanical joints shall be used for reinforcing the steel bar joint. Axial tension members, small eccentric tension members, and vibration-bearing components, and longitudinal stress steel bar joints shall not employ binding joints; welded framework with bilateral stress steel bars shall not employ binding joints; tension steel bars with diameters greater than 28 mm or compression steel bars with diameters greater than 32 mm shall not employ binding joints.
- b) Flash butt welding shall be adopted in steel bar joint processing. When flash butt welding cannot be carried out, arc welding (overlap welding, bar welding, weld groove welding) and mechanical connections (pier thick cone thread joint, pier thick straight thread joint, rib stripping rolling straight thread joint) should be used.
  - 1) A hot-rolled steel bar joint with a diameter greater than 28 mm can be welded by weld groove welding, narrow gap welding or bar welding. Hot-rolled steel bar joints with a diameter less than or equal to 28 mm can be welded by manual arc overlap welding and flash butt welding (factory processing).
  - 2) A steel bar joint with a diameter of 20 mm to 40 mm should be welded by contact electroslag welding (vertical) and pneumatic welding, but when the diameter is greater than

28 mm, the welding method shall be tested and demonstrated before use. It is inappropriate to use contact electroslag welding and gas pressure welding for welded joints with poor weldability.

- 3) HRB335 and HRB400 steel bar joints with specifications of 16 mm to 40 mm can be mechanically connected. When a straight thread connection is adopted, the length for threads of two connected steel bars screwing into the sleeves should be the same.
- c) In field construction, binding overlap welding, manual arc welding (overlap welding, bar welding, weld groove welding, and narrow gap welding), pneumatic welding, and mechanical connection may be adopted. Contact electroslag welding should be used for the welding of vertical or oblique steel bars (inclination within the range of 1 : 0.5).
  - d) Contact spot welding should be used for the cross-linking of steel bars instead of manual electric arc welding.
  - e) The performance index of a steel bar joint with mechanical connection should meet the Grade I standard. After verification and confirmation, Grade II and Grade III joints can be used.
    - 1) Grade I: The tensile strength of the joint is not less than the actual tensile strength of the steel bar to be connected nor less than 1.1 times the standard tensile strength, and the residual distortion is slight, and the joint has high ductility and repeated tensile and compressive properties.
    - 2) Grade II: The tensile strength of the joint is not less than the standard tensile strength of the steel bar to be connected, and the residual distortion is slight, and the joint has high ductility and repeated tensile and compressive properties.
    - 3) Grade III: The tensile strength of the joint is no less than 1.25 times the standard yield strength of the steel bar to be connected, and the residual distortion is slight, and the joint has certain ductility and repeated tensile and compressive properties.
  - f) When construction conditions are limited or specially demonstrated, the type of steel bar connection can be determined according to site conditions.
  - g) Rust, paint, and grease stains in the welding area should be cleaned before steel bars are welded.
  - h) There shall be windbreak and snow protection measures for welding bars in negative temperatures. High-quality welding rods shall be selected for manual arc welding, and ice and snow should be avoided immediately after welding. Special thermal insulation and wind protection measures shall be implemented when welding is performed below  $-15\text{ }^{\circ}\text{C}$ . Reliable rainproof and safety measures shall be implemented if welding is performed outdoors on rainy days. It is un-

suitable for welding at a temperature below  $-20\text{ }^{\circ}\text{C}$ .

- i) Workers who weld steel bars shall be qualified with certificates.

#### 6.5.2.4 Installation of steel bars shall meet the following requirements.

- a) When installing steel bars, parameters such as position, spacing, protective layer and size of distributing bars shall all meet the design requirements. The deviation from these parameters shall be no greater than the values in Table 21.
- b) The thickness of the protective layer shall be strictly controlled when steel bars are being installed. Sufficient quantities of qualified concrete or mortar cushion blocks, whose strengths are greater than design strength, shall be placed under the bars or between the bars and formwork. Iron wires shall be embedded in the cushion blocks on the lateral sides, and shall be fixed to the steel bars. The arrangement of all the cushion blocks shall be dispersed and staggered.
- c) For double layer or multi-layer bars, effective measures such as using short bars between the gaps shall be taken to keep the bars in the correct position.

**Table 21 Allowable error in steel bar installation**

No.	Name of deviation	Allowable error
1	Longitudinal deviation of steel bars	$\pm 1/2$ of the thickness of protective layer
2	Partial deviation of load-carrying bars in the same row: 1) Column and beam; 2) Board and wall	$\pm 0.5d$ ( $d$ is the diameter of bars) $\pm 1/10$ of the space between rows
3	Deviation in the distance between bars arranged in the same row	$\pm 1/10$ of the space between rows
4	Partial deviation of bars between adjacent rows	$\pm 1/10$ of row spacing
5	Deviation of stirrup spacing in the beam and column	$1/10$ of the stirrup spacing
6	Partial deviation of the thickness of protective layer	$\pm 1/4$ of the net thickness of the protective layer

- d) The cross-connecting of steel bars between welded or bound steel meshes shall be carried out in accordance with the provisions of design documents. If the design documents do not have relevant specifications and the steel bar's diameter is less than 25 mm, unless the cross points of two peripheral rows of steel bars inside the floor slabs and walls shall be fixed point by point, the rest cross points shall be fixed at every other point.
- e) The two-way load-bearing bar mesh inside slabs shall be fastened at all crossing points. For steel bar columns and beams, the cross points of the main bars and stirrups at the turning points shall be fastened, and the binding in the middle part may be carried out at every other cross point.

- f) For steel bars HRB235 and HRB335 or steel bars with a diameter greater than 16 mm and if the rebar section will not be damaged, the binding of cross points in steel bar installation can be replaced by spot welding using manual arc welding. However, fine electrodes and low current shall be used for welding, and the appearance should be strictly inspected. The steel bars shall not have obvious undercut or cracks.
- g) Bearing rods shall be erected before steel bar installation, and steel bars with a diameter of not less than 22 mm should be selected for bearing rods. Installed steel bars shall have sufficient rigidity and stability. In the transport and installation process, the prefabricated binding and welding steel bar mesh and rebar framework shall be prevented from undergoing distortion, welding, and loosening.
- h) Steel bars should be properly protected in time to prevent dislocation, distortion, and corrosion after being installed. Detailed inspections should be carried out and inspection records should be completed before concrete is poured. If qualified steel bars are exposed long-term, they should be re-examined and approved in order to be qualified before concrete pouring.
- i) In concrete pouring, the staff on duty shall be arranged to regularly inspect the position of steel bar erection. If any change is found, the position shall be rectified in due time, and the steel bars shall not be moved or cut off without authorization.

### 6.5.3 Concrete

#### 6.5.3.1 The technology requirements for cement quality shall meet the following:

- a) Cement quality shall meet the requirements of current national standards. The cement transported to the construction site shall have quality test reports, and the cement's stability and strength shall be retested in labs. Testing methods shall meet the following requirements:
  - 1) Every 200 t of cement with the same type and strength grade shall be taken as a sampling unit. If the total weight is less than 200 t, it is also taken as one sampling unit. Take equivalent samples from 20 different parts of the cement, mix completely, and take it as one overall sample, whose weight shall be no less than 12 kg.
  - 2) If needed, use the rapid testing method to forecast the 28-day strength of cement as a basis for concrete production control and carrying out design of the mixing proportion.
- b) The cement type shall be selected by design requirements and application conditions. The selection principles are as follows:
  - 1) Portland cement shall be selected as first choice for concrete in water-level-fluctuation zones or with special requirements such as frost resistance, anti-scouring and anti-wear.

- 2) Slag cement, fly-ash cement or pozzolan cement should be selected for concrete for underwater parts which cannot be scoured or in the interior of mass construction components.
  - 3) Medium-heat Portland cement, low-heat Portland cement, and ordinary Portland cement are suitable for internal concrete, underwater concrete and foundation concrete. Low-heat expansive cement, low-heat Portland slag cement, Portland blast furnace slag cement, Portland pozzolan cement, and Portland fly-ash cement can also be used.
  - 4) When environmental water has sulphate attack on concrete, sulphate-resistant Portland cement should be selected.
- c) The strength grade of the cement shall be in accordance with the design strength of the concrete, and shall not be less than 32.5 MPa. The strength grade of concrete in water-level-fluctuation zones or with special requirements such as frost resistance, anti-scouring and anti-wear should be no less than 42.5 MPa.
  - d) Cement shall be stored by different type, strength grade, brand and batch respectively. Attention shall be paid to rain and moisture protection in the transportation and safekeeping process. Cement whose quality has obviously declined due to improper storage, or which was produced in bags three month ago or produced in bulk six months ago, shall be rechecked to determine whether or not the cement is qualified to be used.
  - e) No more than three types of cement should be used in each part of the project. Different types of cement shall not be mixed in use unless this has been demonstrated by testing.

6.5.3.2 Rubble or pebbles can be used as coarse aggregate for concrete, and shall meet the following technical quality requirements:

- a) Coarse aggregates shall be hard, clean, and well-graded. Powder, mud or contamination shall be removed in time.
- b) The maximum diameter of coarse aggregates shall be no greater than 1/4 of the cross-section size of the concrete structure and 2/3 of the minimum net steel bar spacing, nor greater than 1/2 of the thickness of plain concrete slab. For concrete structures with few or no bars, large coarse aggregates shall be selected.
- c) During construction, rubble or pebbles should be divided into several grades by grain size as follows:
  - 1) When the maximum grain size is 40 mm, divide into 5 mm to 20 mm and 20 mm to 40 mm.
  - 2) When the maximum grain size is 80 mm, divide into 5 mm to 20 mm, 20 mm to 40 mm and 40 mm to 80 mm.

- 3) When the maximum grain size is 150 (or 120) mm, divide into 5 mm to 20 mm, 20 mm to 40 mm, 40 mm to 80 mm and 80 mm to 150 (or 120) mm.
- d) The oversize and sub-size content in each grade shall be strictly controlled. For round hole sieve tests, the control standard is that the oversize content shall be less than 5% , while the sub-size content shall be less than 10%. When inspection with an oversize-and-undersize screen (square hole) is performed, the control standard is that no oversize shall occur while undersize is no greater than 2%.
- e) Special verification shall be carried out for rubble or pebbles containing active aggregate or yellow rust.
- f) The crushing index value for coarse aggregate shall comply with Table 22 and other quality requirements shall comply with Table 23.

6.5.3.3 Natural sand or artificial sand can be adopted as fine aggregate for concrete, and its quality technology shall comply with the following requirements:

- a) Fine aggregate shall be hard, clean, and well graded, and the quality meets the requirement in Table 24.
- b) The surface moisture content of fine aggregate should not exceed 6% , and should remain stable. If necessary, accelerated dehydration measures shall be implemented.
- c) The use of mountain sand, sea sand, coarse sand, and extra fine sand shall be tested and demonstrated.
- d) When there are active aggregates in fine aggregate, special tests shall be carried out.

**Table 22 Crushing index values for coarse aggregate**

No.	Aggregate type		Design-age concrete crushing strength grade	
			$\geq 30$ MPa	$< 30$ MPa
1	Gravel	Sedimentary rock	$\leq 10$	$\leq 16$
		Metamorphic rocks	$\leq 12$	$\leq 20$
		Igneous rock	$\leq 13$	$\leq 30$
2	Cobble		$\leq 12$	$\leq 16$



Table 23 Other quality requirements for coarse aggregate

No.	Item		Index
1	Mud content (%)	D20 and D40 grain-size grade	$\leq 1$
		D80, D150 (D120) grain-size grade	$\leq 0.5$
2	Firmness (%)	Concrete with frost resistance and corrosion resistance requirements	$\leq 5$
		Concrete without frost resistance requirements	$\leq 12$
3	Content of soft particles (%)	Design age strength grade $\geq 30$ MPa or concrete with frost resistance requirements	$\leq 5$
		Design age strength grade $< 30$ MPa	$\leq 10$
4	Water absorption (%)	Concrete with frost resistance and corrosion resistance requirements	$\leq 1.5$
		Concrete without frost resistance requirements	$\leq 2.5$
5	Needle and plate particle content (%)	Design age strength grade $\geq 30$ MPa or concrete with frost resistance requirements	$\leq 15$
		Design age strength grade $< 30$ MPa	$\leq 25$
6	Apparent density ( $\text{kg}/\text{m}^3$ )		$\geq 2550$
7	Sulphate and sulphide content (%)		$\leq 0.5$
8	Organic matter content		Lighter than standard colour
9	Clay lump content		Not allowed

Table 24 Quality requirements for fine aggregate

No.	Item	Index	
		Natural sand	Artificial sand
1	Apparent density ( $\text{kg}/\text{m}^3$ )	2 500	
2	Fineness modulus	2.2~3.0	2.4~2.8
3	Stone powder content (%)	—	6~18
4	Surface moisture content (%)	$\leq 6$	
5	Mud content (%)	Design age strength grade $\geq 30$ MPa or concrete with frost resistance requirements	$\leq 3$
		Design age strength grade $< 30$ MPa	$\leq 5$
6	Firmness (%)	Concrete with frost resistance and corrosion resistance requirements	$\leq 8$
		Concrete without frost resistance requirements	$\leq 10$
7	Clay lump content	Not allowed	

Table 24 (continued)

No.	Item	Index	
		Natural sand	Artificial sand
8	Sulphide and sulphate content (%)	≤1	
9	Mica content (%)	≤2	
10	Lightweight matter in aggregate (%)	≤1	—
11	Organic matter content	Lighter than standard colour	Not allowed

6.5.3.4 The water used in mixing and maintaining concrete shall meet the following requirements:

- a) All water that meets drinking water standards can be used, and untreated industrial and domestic sewage shall not be used.
- b) Surface water, groundwater, and other types of water that have been inspected to meet the standards can be used for concrete mixing and maintenance. Inspection items and standards shall also meet the following requirements:
  - 1) Concrete mixing water and drinking water samples shall be tested for cement setting time comparison. Both the cement initial setting time difference and final setting time difference in the test shall not be greater than 30 min.
  - 2) Concrete mixing water and drinking water samples shall be tested for cement mortar strength comparison. The 3-day and 28-day age strength of cement mortar prepared by using the tested water samples shall not be lower than 90% of that of cement mortar prepared by using the drinking water.
  - 3) Concrete mixing water shall meet requirements of Table 25.

6.5.3.5 Concrete admixtures shall meet the following requirements:

- a) The quality of admixtures mixed into concrete shall meet the requirements of the current national standards. The dosage of admixtures shall be determined by tests.
- b) Besides fly-ash which is frequently used, other admixtures such as silicon powder, tuff and phosphorous slag can be used according to local conditions.

Table 25 Concrete mixing water requirements

Item	Reinforced concrete	Plain concrete
PH value	$\geq 4.5$	$\geq 4.5$
Insoluble substance (mg/L)	$\leq 2\ 000$	$\leq 5\ 000$
Soluble substance (mg/L)	$\leq 5\ 000$	$\leq 10\ 000$
Chloride, $CL^-$ (mg/L)	$\leq 1\ 200$	$\leq 3\ 500$
Sulphate, $SO_4^{2-}$ (mg/L)	$\leq 2\ 700$	$\leq 2\ 700$
Alkali content (mg/L)	$\leq 1\ 500$	$\leq 1\ 500$
<b>NOTE</b> The alkali content is expressed by the calculated value of $Na_2O + 0.658 K_2O$ . Alkali content may not be tested when non-alkali active aggregate is used.		

6.5.3.6 The use of admixtures shall meet the following requirements:

- The type of admixtures shall be selected according to the environment where the buildings stand, the concrete properties and the construction requirements.
- Technical parameters of admixtures shall meet the requirements. Products which are not provided by professional manufacturers and have not been proven by testing, shall not be used in projects.

6.5.3.7 The concrete mix proportion shall be determined according to the following requirements:

- The concrete mix proportion shall be determined based on calculations and tests. It shall not only meet the requirements of design strength, durability and workability, but also the economic requirements.
- The water-cement ratio of concrete shall be determined according to design requirements by tests, and should be no greater than the requirements of Table 26.

Table 26 Allowable values of maximum water-cement ratio

Concrete location	Extremely cold areas	Cold areas	Warm areas
Upstream and downstream zones (of the exterior of the dam body) above water	0.50	0.55	0.60
Upstream and downstream zones (of the exterior of the dam body) in water-level-fluctuation locations	0.45	0.50	0.55
Upstream and downstream zones (of the exterior of the dam body) underwater	0.50	0.55	0.60
Foundations	0.50	0.55	0.60
Interior of the dam body	0.60	0.65	0.65
Zones subject to water erosion	0.45	0.50	0.50
<b>NOTE</b> When the dam body is eroded by the surrounding water, the maximum water-cement ratio of concrete shall be reduced by 0.05 outside of water level-fluctuation zones and underwater zones.			

- c) The concrete slump shall be determined according to the properties of the buildings, the steel bar content, the concrete transport and pouring methods and weather conditions. Concrete with as low a slump as possible shall be used. The concrete slump requirements of Table 27 for the pouring site can be used for reference.

**Table 27 Concrete slump on the pouring site**

Type of concrete	Slump (mm)
Plain concrete or concrete with little steel bar	10~40
Concrete with steel bar content less than 1%	30~60
Concrete with steel bar content more than 1%	50~90

**6.5.3.8** The mixing of concrete shall meet the following requirements:

- a) The concrete shall be compounded according to the concrete charger sheet which has been signed and examined by the laboratory. The charger sheet shall not be changed without authorization.
- b) The cement, sand, rubble and solid admixtures shall be measured by weight, while the water and the solution of admixtures can be measured by volume which is converted from weight. The deviation in weighing the aggregate shall be no greater than 2%, while the deviation in weighing the cement, solid admixtures, water and the solution of admixtures shall be no greater than 1%.
- c) The mixing time of concrete shall be determined by tests. If there is no test, refer to the minimum mixing time listed in Table 28.

**Table 28 Minimum mixing time of concrete**

The capacity of mixer (m <sup>3</sup> )	Maximum diameter of coarse aggregate (mm)	Minimum mixing time (s)	
		Setting type mixer	Forcing type mixer
0.8~1.0	80	90	60
1.0~3.0	150	120	75
>3.0	150	150	90

**6.5.3.9** The transport of concrete shall meet the following requirements:

- a) The selection of transport equipment and transport capacity shall be in accordance with the mixing capacity, pouring capacity, the condition of the working surface and steel bars, and the requirements for hoisting and transporting the formwork.
- b) The mixed concrete shall be sent to the concrete bin with the least number of transport cycle

times. Concrete which has already reached preliminary setting shall be treated as waste material.

- c) The roads for transportation shall be as flat as possible to avoid segregation, leaking and great loss of slump; if the concrete has segregated when reaching the pouring site, it shall be mixed again.
- d) The freefall height of concrete should not be greater than 2 m; if the actual drop is greater than 2 m, measures such as slipping tube and serial tube shall be implemented to slowdown the dropping of the concrete.
- e) Containers which are non-absorbent and non-leaking shall be used. Containers shall be moistened with water before use and shall be cleaned afterwards.

**6.5.3.10** Concrete placement shall meet the following requirements:

- a) Before the placement of concrete, technicians shall check the cleaning of the interior of the bins, formwork, steel bars, embedded parts, permanent joints, preformed holes, preparatory work of concrete placement and so on, and keep the inspection records. Only when the acceptance work has been completed can the concrete placement be carried out. For the bins on the bedrock surface and on the old concrete at the upstream face, before pouring the first layer of concrete, a layer of cement mortar or concrete with rich mortar should be poured, whose water-cement ratio shall be 0.03 to 0.05 less than that for concrete.
- b) Concrete shall be poured layer by layer according to different thickness, sequence and direction. The working surface shall be approximately horizontal. Concrete shall be flattened during pouring. Vibrators shall not be used to flatten concrete. Coarse aggregates piled together shall be uniformly dispersed in places where there is more mortar and shall not be covered by mortar. When pouring concrete on the slope, pouring shall start from the bottom and move up layer by layer. Horizontal layering shall be maintained during pouring.
- c) The thickness of the concrete pouring layer shall be determined according to the capacities of mixing, transporting and casting, vibrator properties and temperature, and shall not be thicker than the requirements of Table 29.

**Table 29** The allowable maximum thickness of each concrete pouring layer Unit: mm

Vibrating machine types and vibrating methods		The allowable maximum thickness
Insertion type	Flexible-shaft vibrators	1.25 times the length of the vibrating machine head
Surface type	In concrete with no or little reinforcement	250
	In structure with dense bars or double layer bars	150

- d) The concrete placement shall proceed continuously. If the pause time of placement exceeds the allowable pause time for some reasons, the interface shall be treated as a construction joint. If it can be remodelled, concrete pouring can continue. The pause time (from the time of the beginning of feeding water and mixing to the time when the upper layer of concrete is covered) shall be controlled before the concrete's initial setting, and be determined by tests, or comply with the requirements in Table 30.

**Table 30 Allowable pause time of concrete placement**

Temperature of working surface (°C)	Allowable pause time (minute)	
	Portland cement Ordinary Portland cement	Slag cement, fly-ash cement
20~30	90	120
10~19	150	180
5~9	180	210

**NOTE** This table has not taken the influence of admixtures and other special measures into consideration.

- e) Construction joints shall meet the following requirements:
- 1) The position and form of construction joints shall be determined according to the principle that the joints do not harm the strength and appearance of the structures.
  - 2) Roughening measures such as chiselling, scouring and brushing shall be taken to remove cement films and weak layers on the surface of old concrete according to different hardening degrees. Then wash the surface and drain off the poundings on the surface.
  - 3) Only when the concrete strength has reached 2.5 MPa can the placement of the upper layer concrete be prepared. Cement mortar shall be placed as per the requirements of Item 1) of this Paragraph before pouring the upper concrete.
  - 4) New concrete which is cast on the surface of old concrete shall be carefully tamped.
- f) The concrete shall be vibrated mainly by vibrators, and the vibrating of concrete shall meet the following requirements:
- 1) The vibrators shall vibrate in a certain order to prevent omission of vibrating and repeat vibrating. The vibrating spacing shall not be greater than 1.5 times the vibrator's effective radius; when using the surface vibrators to vibrate, the borders of the vibrating range shall overlap a little.
  - 2) The vibrator heads should be vertically inserted 50 mm into the lower concrete and vibrate for a certain time. When the concrete has no significant sinking and there are no bubbles in

the concrete, bleeding begins to appear on the surface and there is no segregation of the concrete, it is time to bring the machines out slowly to prevent leaving behind voids. Vibration missing and over vibration shall be avoided.

- 3) The distance between the vibrator head and the formwork shall be approximately equal to 1/2 of its effective radius. The vibrator heads shall not touch the bars, waterstop and embedded parts.
  - 4) For zones where vibrators cannot be used or concrete placement is difficult, the method of manual vibrating can be adopted.
- g) The embedding of rocks in the concrete shall meet the following requirements:
- 1) When rocks are embedded in mass concrete structures and in places where embedding rocks are allowed by design drawings or in reinforced concrete structures, the construction and operation shall ensure close connection and compactness of the concrete. It is forbidden to increase the ratio of embedding stone at the cost of reducing the quality of concrete placement.
  - 2) Rock size should range from 300 mm to 400 mm. The maximum size shall be no greater than 1/4 of the minimum size of the concrete block which is to be cast. Flake-shaped and strip-shaped rocks whose length-width ratio is greater than 2.5 : 1 should not be used. Rocks which are fragile, cracked, weathered and intercalated with sand or mud, and whose strength is less than that of coarse aggregate shall not be used.
  - 3) The rocks shall be uniformly laid, rather than tossed, on the newly cast concrete. The clear distance between the rocks and formwork or the boundary of the structures shall be no less than 300 mm. Rocks should not be embedded in concrete used in tension areas which are less than 1m from the foundation and less than 2 m from the upstream face. Sufficient horizontal and vertical distance between blocks of rocks shall be left to make sure the concrete can be fully vibrated.
  - 4) The concrete around the rocks shall be carefully vibrated. The optimal method of construction shall be selected according to the intensity strength of the vibrating equipment.
- h) In concrete placement, attention shall be paid to the following:
- 1) Bleeding water shall be drained off in time, but the mortar shall not be washed away.
  - 2) The stability of formwork and supports shall be checked at any time. If there is any leaking, distortion or sinking, it shall be immediately treated. The position of the bars, waterstop

and embedded parts shall also be checked at any time. If there is any displacement, it shall be immediately adjusted.

- 3) Mortar which adheres to the formwork, steel bars, waterstop and embedded parts shall be removed in time. When the concrete has been poured up to the top, it shall be trowelled at once and the bleeding water shall be drained off. After initial setting, the concrete shall be trowelled again to prevent desiccation fissures on the concrete surface.

6.5.3.11 The maintenance of concrete shall meet the following requirements:

- a) When the concrete has been poured, it shall be covered in time to prevent solarisation. When the concrete on the surface has reached initial setting, it shall be watered in time to keep the concrete surface and formwork moist.
- b) The concrete shall be maintained in a continuously moist environment for at least 28 days. This duration time should be extended for some parts with special requirements.

6.5.3.12 The inspection and quality control of the concrete shall meet the following requirements:

- a) When the concrete is being processed, the inspection of raw materials shall meet the following requirements:
  - 1) The aggregate transported to the construction site shall be inspected, and each batch shall be inspected at least once.
  - 2) The cement, admixtures and compounds shall have product certifications, and samples shall be taken for inspection. Cement in bags produced more than three months ago shall be re-inspected and shall be inspected by sampling before it enters the storehouse.
  - 3) The water which is used to mix and maintain the concrete shall be rechecked if the source of water changes or there is any doubt about the water.
- b) The quality inspection of concrete placement shall meet the following requirements:
  - 1) The water content of sand and pebbles shall be inspected at least once each shift. The number of inspection times shall be increased on days with significant temperature differences or on rainy days. The charger sheet shall be adjusted at any time according to the measured water content.
  - 2) The dosage of the raw materials used in mixing concrete shall be inspected at least twice each shift. The weighing apparatus shall be randomly inspected and regularly adjusted.



- 3) The mixing time of concrete shall be inspected at least twice each shift.
  - 4) The concrete slump on site shall be inspected at least twice each shift at the outlet from the batch mixers and at least twice each shift on the surface of the bins. When processing specimens, the concrete slump shall be measured at the same time.
  - 5) The concentration of solution of admixtures shall be inspected 1 to 2 times each day. The air content of concrete with air entrainer shall be inspected, and the variation range shall be controlled to within  $\pm 1.0\%$ .
- c) The quality of solidified concrete shall be inspected with the compaction strength of specimens which have been maintained for 28 days under standard conditions (the temperature shall be between  $17\text{ }^{\circ}\text{C}$  and  $23\text{ }^{\circ}\text{C}$  and the relative humidity shall be greater than 95% or be immersed in water) as the evaluation index. Some other tests such as tensile, frost resistance and anti-seepage tests shall be conducted if needed. The groups of specimens used in the compaction tests shall be processed and selected according to the following requirements:
- 1) The specimens shall be respectively processed from concrete with different strength grades and mix proportions.
  - 2) One group of specimens shall be processed from every  $500\text{ m}^3$  of concrete in large mass concrete structures.
  - 3) One group of specimens shall be processed from every  $100\text{ m}^3$  of concrete in small concrete structures. At least one group of specimens shall be processed from each part of the project.
  - 4) At least one group of specimens shall be processed during each shift.
  - 5) The concrete specimens shall be randomly sampled and moulded at the outlet from the batch mixer, and shall not be intentionally selected. A certain number of specimen groups should be tested at the placement site. Three specimens in one group shall be processed from the same batch of concrete.
- d) The concrete sample strength shall be assessed in accordance with the following requirements. The calculation of  $\bar{f}_c$ ,  $m_{fcu}$ , and  $P$  are shown in Appendix F.
- 1) When groups of concrete blocks with the same label (or strength grade) reaching 28-day compressive strength are  $n \geq 30$ , the requirements in Table 31 shall be met.

Table 31 Quality standard for the 28-day compressive strength of concrete blocks

Item	Quality standard	
	Good	Qualified
The lowest compressive strength of any test block shall not be lower than the design value.	90%	85%
Strength assurance ratio of concrete without steel bars (or less steel bars)	85%	80%
Strength assurance ratio of bar-reinforced concrete	95%	90%
Deviation coefficient of concrete compressive strength	<20 MPa	<0.18
	≥20 MPa	<0.14
		<0.22
		<0.18

- 2) When groups of concrete blocks with the same label (or strength grade) reaching 28-day compressive strength are  $30 > n \geq 5$ , the strength of the concrete blocks shall meet the Formula (9), (10) and (11) requirements at the same time:

$$m_{fcu} - 0.7\sigma > R_d \quad \dots\dots\dots (9)$$

$$m_{fcu} - 1.6\sigma \geq 0.83R_d \text{ (when } R_d \geq 20) \quad \dots\dots\dots (10)$$

$$\text{or } \geq 0.80R_d \text{ (when } R_d < 20) \quad \dots\dots\dots (11)$$

where

$\sigma$  is the standard deviation of concrete strength is calculated according to methods in Appendix F;

$m_{fcu}$  is the average strength of  $n$  specimens, in MPa;

$R_d$  is the design 28-day compressive strength value, in MPa;

$n$  is the sample size.

- 3) When the groups of concrete blocks with the same label (or strength grade) reaching 28-day compressive strength are  $5 > n \geq 2$ , the strength of concrete blocks shall meet the Formula (12) and (13) requirements at the same time:

$$m_{fcu} \geq 1.15R_d \quad \dots\dots\dots (12)$$

$$m_{fcu, i-\min} \geq 0.95R_d \quad \dots\dots\dots (13)$$

where

$m_{f_{cu,i,min}}$  is the value for the group with the minimum strength among  $n$  groups of test blocks, in MPa.

- 4) When there is only one group of concrete blocks with the same label (or strength grade) reaching the 28-day compressive strength, the strength of the concrete blocks shall meet the Formula (14) requirements at the same time:

$$m_{f_{cu,i}} \geq 1.15R_d \quad \dots\dots\dots ( 14 )$$

where

$m_{f_{cu,i}}$  is the measured strength value of test block, in MPa

- e) When the concrete specimen strength cannot meet the requirements, non-destructive evaluation methods, such as taking concrete samples from the structures, shall be adopted for re-inspection. If the results still cannot meet the requirements, the safety degree of the structures shall be recalculated in the actual conditions or some necessary reinforcement measures shall be taken.
- f) The allowable error of non-mass cast-in-place concrete structures shall meet the requirements of Table 32, and shall also meet relevant special requirements if any.

**Table 32 Allowable error of non-mass cast-in-place concrete structures** Unit: mm

Items		Allowable error
The position of axis	Foundation	15
	Independent foundation	10
	Structures such as walls, columns and beams	8
Verticality (H is the total height of the structures)	$H \leq 5$ m	8
	$H > 5$ m	$H/1\ 000, \leq 30$
Elevation		$\pm 10$
Section size		+8, -5
The evenness of surface (in a 2 m length)		8
The position of centre lines of embedded facilities	Embedded parts	10
	Embedded bolts	5
	Embedded tubes	5
The position of centre lines of preformed holes		15

- g) Enhance the observation and inspection of the concrete defects. Analyse the reasons, properties

and degree of harm of the defects to make reinforcement plans. The treatment of concrete defects shall meet the following requirements;

- 1) Subtle surface fissures and shallow fissures of reinforced concrete whose width is less than the allowable values of Table 33 can be left alone. Fissures whose width is larger than the allowable values, and those which have changed the properties of structures, such as voids and pits in the concrete, shall be treated according to the relevant requirements.

**Table 33 Allowable values of the maximum fissure width of reinforced concrete structures**

Unit: mm

Above water area	Water-level-fluctuation zone		Underwater area
	Cold area	Warm area	
0.20	0.15	0.25	0.30

- 2) The strength of material which is used in strengthening the concrete shall be larger than that of the concrete, while the distortion properties should be close to those of concrete. Active fissures shall be repaired by flexible materials.
  - 3) Concrete fissures shall be repaired when they have reached steady state, and should be repaired during a season with lower temperatures, when the width of the fissures is bigger.
  - 4) The treatment of concrete defects shall be properly recorded when the defects have been repaired.
- h) During the process of concrete construction, the following items shall be properly recorded in time;
- 1) The amount of concrete in each member or block, the weight of raw materials, the strength grade and mix proportion of the concrete.
  - 2) The order of casting of concrete members and blocks, the starting and ending time of placement, the quality accidents and the treatment of accidents, the time and method of maintenance and surface protection.
  - 3) The temperature of the casting site, the temperature of the raw materials and concrete when they are poured, the date of form stripping in different parts.
  - 4) The results and analyses of the concrete specimen tests.
  - 5) The parts where concrete defects exist, the date when they were formed, and how the situation is developing.
  - 6) Other relevant matters.

6.5.3.13 Concrete construction during low temperature seasons shall meet the following requirements:

a) General provisions

- 1) When the average daily temperature stays below 5 °C for 5 consecutive days or the minimum temperature stays below -3 °C for 5 consecutive days, the construction shall be carried out in accordance with the low temperature season.
- 2) During construction in a low temperature season, special construction organization design and technical measurements must be compiled to ensure that the poured concrete meets the design requirements.
- 3) The allowable frozen critical strength of concrete at early age shall meet the following requirements:
  - Mass concrete shall not be less than 7.0 MPa (or maturity not less than 1 800 °C · h).
  - Non-mass concrete and reinforced concrete shall not be less than 85% of the design strength.
- 4) In a low temperature season, especially in cold areas, construction sites shall not be scattered. Before entering the low temperature season, the concrete that has been poured with the requirement of insulation shall adopt the insulation measures.
- 5) In the low temperature season, heating, thermal insulation and anti-freeze materials (including early strength and anti-freeze additives) shall be prepared before construction, and fire prevention measures shall be taken.

b) Construction preparation

- 1) Storage, heating, transportation of raw materials and mixing, transportation and pouring of concrete storehouse surface shall be based on climatic conditions through thermal calculation to select appropriate thermal insulation measures.
- 2) The aggregate shall be screened and washed before entering the low temperature season. The finished materials shall be adequately stored and piled high, and measures shall be taken to prevent ice, snow and freezing.
- 3) In low temperature season, concrete mixing water shall first be heated. When the average temperature of the day is stable below -5 °C, the aggregate shall be heated. The steam pipe method is suitable for aggregate heating. Coarse aggregate can be directly heated by steam, but the water-cement ratio of the concrete should not be affected. When aggregates

need not be heated, pay attention not to freeze them, and do not mix them with ice and snow.

- 4) Before mixing concrete, wash the mixer with hot water or steam and remove water.
- 5) Before pouring concrete on rock foundation or old concrete, the surface temperature shall be measured. If it is negative temperature, it shall be heated to positive temperature. The depth of heating shall not be less than 100 mm or the surface temperature shall be positive temperature (higher than 0 °C) at the side and corner (the coldest place) of the storehouse surface. Concrete can be poured after passing inspection.
- 6) Hot air gun or mechanical method shall be used for storehouse surface cleaning, and a water gun or air-water gun shall not be used.
- 7) When the first layer of foundation concrete is poured on a soft foundation, the foundation soil cannot be frozen.

c) Construction methods and insulation measures

- 1) The construction method of concrete in low temperature season shall comply with the following requirements:
  - Heat storage method shall be adopted in temperate areas;
  - Windproof facilities shall be adopted in areas with strong wind and sand. When the wind and sand are strong, and the storehouse surface are not suitable for building greenhouse, the method of laying heating pipes under the thermal insulation cover can be used;
  - Heat storage method shall be adopted when the daily average temperature is above -10 °C in severe cold and cold regions;
  - Comprehensive heat storage method or greenhouse method can be used when the daily average temperature is above -15 °C to -10 °C ;
  - In extremely cold areas (the average temperature difference between the hottest month and the coldest month is more than 42 °C), Construction plan shall be carefully formulated during the low temperature season construction;
  - Except for the special needs of the project, it is not suitable to construct below the daily average temperature of -20 °C.
- 2) The pouring temperature of concrete shall meet the design requirements, but it shall not be

lower than 3 °C in warm areas; the heat storage method shall not be lower than 5 °C in severe cold and cold areas, and the greenhouse method shall not be lower than 3 °C.

- 3) When the steam heating or electro-thermal method is used in construction, special design shall be carried out.
- 4) The use of heat storage in warm and cold areas shall comply with the following regulations:
  - The insulation formwork shall be tight and the insulation layer shall be overlapped firmly, especially in the holes and joints, so as to ensure the construction quality.
  - Wind-proof and heat insulation facilities shall be added to the parts with holes and windward sides.
  - The insulation shall be covered immediately after pouring.
  - Use heat insulation materials that are not easy to absorb moisture.
- 5) The external insulation layer must be firmly fixed on the formwork. The surface of the heat insulation layer of the formwork shall be flat, and reliable measures shall be taken to ensure that the mould can be attached to the concrete surface.
- 6) The mixing time of concrete shall be appropriately extended as compared to that of a normal temperature season, which shall be determined by experiments. When aggregate and concrete are heated, it is advisable to shorten the transportation distance and reduce the amount of transportation.
- 7) In the construction process, the exit temperature of the concrete shall be controlled and adjusted in time to minimize fluctuation and keep the pouring temperature uniform. The optimum control method is to adjust the mixing water temperature. The method of increasing the temperature of concrete mixtures:
  - First of all, heating the mixing water shall be considered;
  - When heating the mixing water cannot meet the pouring temperature requirements, the aggregate shall be heated.
  - The cement must not be heated.
- 8) When mixing water is heated to over 60 °C, the mixing and feeding sequence should be changed. The aggregate and water shall be mixed first, then cement shall be added to avoid cement false setting.

- 9) After the concrete is poured, the exposed surface shall be insulated in a timely manner. The joints and corners of new and old concrete shall be well-insulated. The thickness of the insulation layer shall be twice that of other insulation layer. The overlap length of the insulation layer shall not be less than 300 mm.
  - 10) For concrete poured during low temperature season, the removal of formwork shall comply with the following requirements:
    - When the non-load-bearing formwork is removed, the concrete strength must be greater than the critical strength or maturity value that allows freezing.
    - The removal of load-bearing formwork shall be determined by calculation.
    - The time for mould removal and the protection after mould removal shall meet the temperature control and crack prevention requirements, and the internal and external temperature difference shall not exceed 20 °C nor shall the concrete surface temperature drop within 2 days to 3 days exceed 6 °C.
  - 11) When inspecting the quality of the concrete, in addition to inspecting the forming specimens according to the regulations, non-destructive testing or maturity method can be used to inspect the early strength of concrete at any time.
- d) Temperature observation
- 1) During the construction period, the temperature observation is stipulated as follows:
    - External temperature shall be measured by an automatic temperature measuring instrument. If manual temperature measurement is used, it shall be measured four times a day.
    - The temperature measurement in the greenhouse is done every 4 hrs, with the temperature 500 mm away from the concrete surface as the standard. The average value for the four corners and the centre temperature is the temperature in the greenhouse.
    - The temperature of the water, admixture and aggregate is measured every hour. When measuring the temperature of the water, admixture solution and sand, the insertion depth of the temperature sensor or thermometer shall not be less than 100 mm. When measuring the temperature of coarse aggregate, the insertion depth shall not be less than 100 mm and shall be 1.5 times greater than the aggregate size, and the surrounding area is filled with fine particles. When measuring with a flash point thermometer, it shall be sampled below 150 mm.
    - The exit temperature of the concrete, the temperature loss during transportation and



the pouring temperature shall be measured as required or every 2 hrs. The insertion depth of the temperature sensor or thermometer is not less than 100 mm.

- The temperature inside the poured concrete block can be measured by resistance thermometer or thermocouple or buried temperature measuring hole (the depth of the hole shall be greater than 150 mm, and the liquid medium fills in the hole), and measured by temperature sensor or glass thermometer.
- 2) The temperature changes of mass concrete shall be noted within 3 days after pouring: the highest and lowest temperatures of external concrete shall be noted every day; the internal concrete shall be noted once every 8 hrs. It shall be noted once every 12 hrs afterwards.
  - 3) During a period of abrupt temperature drop and cold wave, the frequency of temperature measurements shall be increased.

**6.5.3.14** The construction of concrete during high-temperature seasons shall meet the following requirements:

- a) The temperature of concrete placement shall be controlled, and the maximum temperature shall not be higher than 28 °C.
- b) In order to reduce the temperature of concrete placement and prevent the temperature from rising again, the following measures should be taken:
  - 1) Pre-cool the raw material, and pile the aggregate up to a certain height (higher than 6 m to 8 m) for a certain time. When using the materials, take them from the bottom of the material pile. Spray the coarse aggregate with groundwater. Use groundwater or low-temperature water to mix the concrete.
  - 2) Place the concrete in the morning, evening or night as much as possible.
  - 3) Reduce the transport time of the concrete, and increase the casting speed of the concrete and cover the concrete bins.
  - 4) Sun shading measures shall be taken for the concrete transport machines.
  - 5) Sun shading measures shall be taken on the surface of bins. Spray water to reduce the temperature.
- c) To reduce the heat of concrete hydration, cement with lower heat production shall be adopted. Comprehensive measures such as using more admixtures, using aggregate with larger diameter, improving the aggregate gradation and processing concrete with lower flow regime or dry concrete shall be taken to reduce unit cement consumption.

- d) The poured concrete should be covered and maintained as soon as possible. In high temperature seasons, the surface running water method can be used to cool the concrete if conditions permit.

**6.5.3.15** The connection and installation of waterstops shall meet the following requirements:

- a) Copper waterstops shall be even, and all of the scraps, rust and oil stains on the surface shall be cleared away. Sand holes, tack holes or fissures shall be welded together.
- b) The extended parts of copper waterstops should be connected by overlap welding. The overlapping length shall be no less than 20 mm. Both sides of the overlapping parts shall be welded together, including the nose shaped parts. The method of butt welding can also be used if the welding quality has been proved by tests. Manual electric-arc welding shall not be used.
- c) The surface of welding joints shall be smooth and without leaks, sand holes or fissures. Joints which were welded in the factory shall be checked by sampling, and the number of checked joints shall be no less than 20% of the total number of joints. Joints which were welded on site shall be checked by appearance and infiltration tests done one by one.
- d) Copper waterstops shall be installed precisely and firmly. The deviation between the centre line of the nose shaped parts and the centre line of joints shall be within the range of  $\pm 5$  mm. When the position has been fixed, plastic material shall be filled in the cavity of the nose-shaped parts.
- e) PVC or rubber waterstops with distortion and fissures shall not be used.
- f) The method of vulcanized thermal bonding should be adopted for the connecting of rubber waterstops. Connection of PVC waterstops shall follow the requirements of the manufacturer. The thermal bonding method (the overlapping length shall be no less than 100 mm) can be adopted. The joints shall be checked one by one to make sure there are no bubbles, slag inclusion or false welding.
- g) The strength of waterstop joints shall be checked if necessary. The tensile strength shall be no less than 75% of the parent metal's strength.
- h) The joints of copper waterstops and PVC waterstops should be connected by bolting, commonly known as "plastic wrapping the copper". The bolting length should be no less than 350 mm.
- i) When installing the waterstop, it shall be firmly clamped and supported by formwork in the correct position.
- j) Horizontal construction joints should not be set up within a range of  $\pm 500$  mm from a horizontal waterstop. If this cannot be avoided, measures shall be taken to embed or retain the waterstop.

**6.5.3.16** The processing and installation of asphalt felts shall meet the following requirements:

- a) According to the temperature, select the right kind of asphalt as the raw material from No.30 and No.10. If the temperature is high, measures shall be taken to prevent the asphalt from flowing.
- b) The field used for processing the asphalt felts shall be flat. Pave one layer of felt, spread a layer of asphalt uniformly and then repeat the steps above.
- c) The asphalt felts should be set on the formwork of previously cast parts to make sure the felts can be closely connected to both the earlier and the subsequently cast concrete.
- d) The asphalt felts shall be on the same vertical surface as the nose-shaped parts of the waterstop.

**6.5.3.17** The construction of preformed asphalt holes shall meet the following requirements:

- a) The ekstexine (the outer wall) of precast concrete units with preformed holes shall be chiselled, and the joints of the precast concrete units shall be closely sealed up.
- b) The precast units should be assembled joint by joint, and hot asphalt poured joint by joint. Heating elements shall be installed in the holes when adopting the method of pouring the asphalt at one time.

**6.5.3.18** Pipes which are embedded into the concrete shall meet the following requirements:

- a) The type, size, number and embedded position of pipes shall follow the requirements of the design documents.
- b) The embedded pipes shall have no sand holes or blocked parts. Rust, oil stains, scraps or paint on the surface of the pipes shall be cleared away.
- c) The pipes can be connected by screw threads, flanges or other methods such as welding. The connection of joints shall be firm. When welding, any burning debris produced shall not block the pipes or reduce the sectional area of the pipes.
- d) The embedded pipes shall be checked by pressurised water or compressed air to find out whether the pipes are blocked or have any leakage. If so, the problems shall be resolved as soon as possible.
- e) The exits and entrances of the pipes shall be marked by different colours or numbers. Pipes formed in groups shall be carefully checked to avoid any mistake. Pipe openings shall be temporarily closed by plugs, soldering seal or screw thread covers to prevent sundry matter from blocking the pipes.

- f) The sectional area of bent parts in the pipes shall be no less than the original section.
- g) The embedded pipes shall be firmly installed to prevent them from being damaged by impacts or being hit in the process of concrete placement.
- h) Specially-assigned persons shall remain at the site of concrete placement to make sure the problems can be handled in time.

**6.5.3.19** In general, underwater concrete is cast by the direct lift conduit method. The placement of underwater concrete shall meet the following requirements:

- a) The number and position of conduits shall be determined by the casting scope and the working radius of the conduits. In general, the working radius of conduits shall be no larger than 3 m.
- b) During the casting process, the conduit shall only move up and down. Moving it left or right is not permitted.
- c) At the beginning of casting, the bottom of the conduit shall be 50 mm to 100 mm away from the foundation surface, and shall be above the low-lying parts of the foundation.
- d) The maximum grain size of coarse aggregate in the concrete shall be no larger than 1/4 of the inner diameter of the conduit and 1/4 of the clear spacing of bars, and should be no larger than 60 mm as well. The concrete slump should be between 150 mm and 180 mm, and can be smaller at the beginning and larger at the end to automatically make the concrete surface flatten.
- e) In the casting process, the conduit shall be filled with concrete, and the bottom of the conduit inserted and kept in the poured concrete to make sure the concrete is isolated from water.
- f) If the supply of concrete stops for some reason, measures shall be taken to prevent voids from forming in the conduits. If the stoppage lasts a long time, only when the strength of the old concrete has reached 2.5 MPa and the weak layer on its surface has been removed can the placement of new concrete be continued.
- g) The concrete shall be poured to a height which is about 100 mm higher than the design elevation so that the surface concrete of lower strength can be removed.
- h) Impermeability tests shall be conducted on all the conduits. Only impermeable conduits can be used in the placement of concrete.
- i) The underwater concrete placement shall be properly recorded.

**6.5.3.20** Treatment of pre-placed aggregate of grouted concrete shall meet the following requirements:

- a) The treatment of grouted concrete shall meet the design requirements and operation specifications.
- b) The grouting parts of the project shall be cleaned out, and the weak parts of repaired projects shall be chiselled away.
- c) The formwork used in concrete placement shall not only comply with the requirements of this document, but it also needs to be specially designed to make sure there is no leakage and over-size distortion during the grouting process.
- d) The minimum grain size of aggregate used in grouted concrete shall be no less than 20 mm and shall be densely placed according to the design gradation to reduce voids. Fine sand whose grain size is larger than 2.5 mm shall be removed by sieving.
- e) Admixtures shall be added into the mortar to add to the liquidity of the grouted concrete. If the grouting pressure is low, a certain amount of expansion agent, whose dosage shall be determined by tests, should be added into the mortar so that the grouted concrete has a little expansibility before it reaches initial set. The mortar shall pass through a piece of screening cloth with 5 mm × 5 mm pore size before entering the pump to prevent impurities from being mixed into the mortar.
- f) The grouting of mortar shall be uninterrupted, going up gradually from bottom to top. The grouting pressure shall be between 0.1 MPa and 0.5 MPa, and the rising speed of the mortar should be between 500 mm/hr and 1 000 mm/hr. Distortion of formwork shall be closely observed during the grouting process.
- g) Sighting tubes and vent-pipes shall be embedded in the grouting parts to monitor the grouting process. Water pressure tests shall be conducted in the borehole when the grouted concrete has reached final set according to design requirements. Samples shall be taken to perform physical mechanical tests.

6.5.3.21 The pumping of concrete shall meet the following requirements:

- a) The maximum diameter of aggregate grains shall be no larger than 1/3 of the conduit diameter. It is not allowed for oversize aggregate to enter the concrete pump. The sand content should be controlled to be between 40% and 50%.
- b) The concrete slump should be no greater than 180 mm.
- c) The proper amount of admixtures should be added into the concrete.
- d) The dosage of colloid materials such as cement and admixtures should be greater than 300 kg/m<sup>3</sup>.

- e) Before installing the conduit, the dirt and cement mortar shall be cleared away and washed by pressurised water. Before installing, the conduit shall be checked regularly to prevent leaking. Before pumping the concrete, cement mortar shall be pumped through the conduit.
- f) The concrete shall be pumped continuously. The receiving table shall have enough concrete to prevent air being sucked in and causing blockage. If the process is suspended, the concrete pump shall be kept running to prevent blockage of the conduit. At normal temperatures, if the pause time is greater than 45 min, any concrete remaining in the conduit shall be discharged and washed off.

**6.5.3.22** Roller compacted concrete shall comply with the following provisions:

- a) The selection of design parameters of the roller compacted concrete (RCC) mix ratio:
  - 1) Water-binder ratio: It shall be determined according to the design requirements of concrete strength, impermeability, frost resistance and tensile distortion, and its value shall be no more than 0.65.
  - 2) Sand ratio: The best sand ratio value shall be selected by experiment. When using natural coarse aggregate, the sand ratio of three-graded RCC is 28% to 32% , and that of two-graded RCC is 32% to 37%. When using artificial coarse aggregate, the sand ratio shall be increased by 3% to 6%.
  - 3) Unit water consumption: It can be selected according to the VC value of RCC, aggregate type, maximum particle size, sand ratio, stone powder content, admixtures and additives.
  - 4) Admixture: The type and content of admixtures shall be determined by experiment. When the admixtures exceed 65% , special test and demonstration shall be performed.
  - 5) Additives: The variety and amount of additives shall be determined by experiment.
- b) The VC value of RCC mixtures shall be 2 s to 12 s on site. The VC value of the exit shall be dynamically selected and controlled according to the change in climatic conditions at the construction site. It shall be 2 s to 8 s.
- c) The amount of cementitious material used in RCC for permanent buildings shall be no less than 130 kg/m<sup>3</sup>. When it is less than 130 kg/m<sup>3</sup> , it shall be demonstrated by special experiment.

**6.6** Stone masonry works

**6.6.1** The rock material used for masonry shall be of hard texture, fresh and complete. Masonry rock can be divided into four kinds according to shape: rubble, rock block, coarse rock or pebble.

- a) Rubble: irregular shape, weight shall be greater than 25 kg, the central thickness shall be no less than 200 mm. Smaller rubble, also called flagstone can be used to plug joints, but the amount shall not exceed 10% of the weight of the masonry.
- b) Rock block: upper and lower surfaces should be smooth, without sharp corners, and the thickness shall be greater than 200 mm.
- c) Coarse rock: including chipped ashlar and irregular shaped stones, and shall be angular; the six surfaces should be smooth, the maximum height difference on one face should be 1% to 3% of the stone's length. Stone length should be greater than 500 mm, block height should be greater than 250 mm, length-thickness ratio should not be greater than 3.
- d) Pebbles: ellipsoidal shape is appropriate, with long axis no less than 200 mm.

6.6.2 The physical and mechanical properties of the masonry rock material shall be in accordance with the regulations of Table 34.

6.6.3 Before using the rock material, its label shall be identified, and measurement of the physical and mechanical indices shall be carried out. The selection can be made with reference to Appendix K when there is no test data.

6.6.4 The cementing materials for the masonry are mainly cement mortar and concrete. In addition, mixed cement mortar and lime mortar can be used as cementing materials for minor masonry works.

6.6.5 The strength grades of common cement mortars used in the masonry body are M5, M7.5, M10 and M12.5, and the strength grades of concrete are C10 and C15. The strength grades of mixed cement mortar are M2.5, M5, M7.5 and M10, and the strength of lime mortar is 0.1 MPa to 1.0 MPa.

**Table 34 Physical and mechanical properties standards for masonry rock materials**

Items	Standard
Natural density	No less than 2.4 t/m <sup>3</sup>
Saturated ultimate compressive strength	Design rules
Maximum water absorption	No more than 10%
Softening coefficient	In accordance with design stipulation; no less than 0.7 is appropriate without design stipulation
Frost-resistance grade	Reach the design grade

6.6.6 The cement, sand, rock and water used for cementing materials shall be in accordance with the regulations of 6.5.3.1 to 6.5.3.4 (the chlorine ion content in water is not regulated). For the lime used in mixed cement mortar and lime mortar, quick lime shall be cured to hydrated lime by adding water, and then sifted with sieves of 6 mm to 8 mm pore size.

6.6.7 The mixing ratio of the cementing material shall be determined by tests, and shall comply with the following requirements:

- a) Weight ratio shall be used. The weight can be converted to volume when using mixed cement mortar and lime mortar.
- b) Preparation principles, strength and water-cement ratio shall be in accordance with the regulations in 6.5.17.
- c) The proportion of sand content in the concrete mix shall be a little higher than that derived from testing.
- d) The workability of cementing material is evaluated comprehensively by sinking degree (or slump), degree of bleeding water and usability for construction. The sinking degree of cement mortar shall be 40 mm to 60 mm, and the concrete slump shall be 50 mm to 80 mm.

6.6.8 The mixing and transportation of cementing material shall be in accordance with the following requirements:

- a) The allowable deviation in the proportion and weight shall be in accordance with the regulations in 6.5.3.8, and the allowable deviations for other materials are 5% for soil and 3% for lime.
- b) The mixing time for cementing material: no less than 2 min for mechanical mixing, and for manual mixing, the material cannot be used until the colour is uniform after wet-mixing, and dry-mixing shall be carried out no less than 3 times before wet-mixing. For projects which are concentrated and with huge construction quantities, mechanical mixing shall be selected to ensure the uniformity of the cementing material.
- c) Cementing material shall be used at the same time as the mixing. The allowable interval time (from the time the material is ready until the masonry is finished) shall be in accordance with the regulations in Table 30.

6.6.9 Quality control and inspection for cementing material shall be in accordance with the following requirements:

- a) The inspection of cement shall be in accordance with the regulations in 6.5.3.1, 6.5.3.12. Besides, the following items shall be tested: strength grade of cement, solidification time, normal consistency and fineness.
- b) The inspection of sand, rock and water as well as quality tests on mortar and concrete during preparation shall be performed in accordance with the regulations in 6.5.3.12; besides, sampling inspection of the sinking degree of mortar shall be carried out at least twice for each class.



- c) There shall be a set of finished cementing material specimens of the same grade which have been in place and aged for 28 days for every 100 m<sup>3</sup> to 200 m<sup>3</sup> of constructed masonry. There shall be at least 1 set of finished specimens for each part of the project.
- d) The standard for the strength of specimens shall be in accordance with the regulations in 6.5.3.12.

**6.6.10** The connection of masonry and bedrock and the treatment of bedding plane shall be in accordance with design regulations, and according to the following requirements when there are no design regulations:

- a) After the excavation of the masonry foundation according to design requirements, cleaning shall be carried out to smooth sharp corners, remove loose rock and sundry material, and swill out and drain water.
- b) Wet the bedrock surface before pouring cushion layer concrete, and lay a sheet of cement mortar with a thickness of 30 mm to 50 mm and strength greater than M10. The laying area shall match the pouring strength. Then pour the cushion layer concrete according to design regulations.
- c) Preparatory work for the stone masonry upper layer shall not be carried out until the compressive strength of the poured cushion layer concrete or the cementing material on the bedding layer has reached 2.5 MPa.
- d) The scum on the surface of the masonry layer shall be swilled out, and no water left, and surface roughening shall be carried out for a smooth cementing material surface.

**6.6.11** The construction of cement-stone masonry shall be in accordance with the following requirements:

- a) The accuracy in measuring the samples of masonry structures shall be in accordance with the regulations in 4.1.1.
- b) The bed mortar method shall be used in the bricklaying of cement-stone masonry. The basic requirement is level, steady, dense and staggered joints.
  - 1) Level: The bricklaying shall be carried out layer by layer, and the surfaces of the same layer should be on the same level. The height difference should be less than 20 mm to 30 mm between adjacent masonry blocks.
  - 2) Steady: The placement of the stone shall be self-stable, with its larger surface facing downwards, and made steady by shaking or knocking as appropriate.

- 3) Dense: the rocks shall not be in direct contact, and the bed mortar and mortar or concrete filling in vertical seams shall be full and dense. The concrete masonry bed mortar between the joints (horizontal seams) shall not be kept suspended by large aggregate, and the mortar shall be uniformly spread. Internal vibration shall be carried out after filling the vertical seams by mortar. Concrete shall be mechanically vibrated, and the distance between adjacent vibration points shall be no greater than 1.5 times the radius of the vibrating action. If the width of the vertical seam is greater than 50 mm, plugging with flagstones after filling with mortar can be adopted.
  - 4) Staggered joints: On the same bricklaying layer, adjacent stones shall be laid with staggered joints and there shall be no sequential seam along the flow direction. For stones laid above each other on adjacent layers, staggered joints are also required to avoid vertical sequential seams. T-shaped stones could be placed vertically at certain intervals.
- c) The width of seams in the masonry of common piers, walls, dams and arch rings shall be in accordance with the regulations in Table 35.

**Table 35 Allowable width of seams in cement-stone masonry** Unit: mm

Type		Pier/wall/dam			Arch ring
		Coarse rock	Rock block	Rubble	Coarse rock
Cement-stone masonry	Horizontal seam	15~20	20~25	—	15~20
	Vertical seam	20~30	20~40	—	10~20

- d) The allowable bricklaying deviation for the size and location of the cement-stone masonry shall be in accordance with the regulations in Table 36.
- e) The exposed face of the masonry should be cured in a timely way within 12 hrs to 18 hrs after pouring, and the face shall be kept constantly moist. Curing time for cement mortar masonry should be 14 days, and for concrete masonry it should be 21 days.

6.6.12 The bricklaying of cement-stone masonry piers and walls shall meet the following requirements:

- a) The level difference of temporary break-joints shall be no greater than 1.0 m, and gentle benching shall remain.
- b) The bricklaying order of cement-stone masonry piers and walls shall be to first lay the corner stones, then the cladding stones, and lay the filler stones last. The thickness of the cladding stone shall be no less than 300 mm.

Table 36 Allowable deviation for the size and location of masonry Unit: mm

Item	Rubble, rock block			Coarse rock			Arch ring masonry	Cement-stone masonry dam	
	Foundation	Wall/pier	Retaining wall	Foundation	Wall/pier	Retaining wall		Overflow dam	Non-overflow dam
Axial displacement	20	15	50	15	10	30	Allowable deviation of Span $L$ : $\pm L/1\ 000$ Allowable deviation of rise of arch: $\pm L/3\ 000$	10	10
Elevation of foundation and top face	$\pm 25$	$\pm 15$	$\pm 20$	$\pm 15$	$\pm 15$	$\pm 15$	+0, - 5	Weir crest face elevation $\pm 10$	Top surface elevation $\pm 30$
Masonry thickness	+ 30	+ 2 - 10	Not less than design	+ 15	+ 10 - 5	Not less than design	Not less than design, not more than 3% of design	Planar contour $\pm 20$	Layered planar contour $\pm 40$
Perpendicularity or slope of wall	—	30	0.5% $H$	—	25	0.5% $H$	Deviation of the location of the side of arch ring and spandrel masonry from design + 30, - 010	—	—
Surface flatness (within a 2 m length)	—	20	30	—	15	30	Dislocation of the surfaces of adjacent masonry shall be no larger than 5	20	30

- c) The pattern of the bricklaying for cement-stone masonry piers and walls shall be with internal and external overlapping, and alternate staggered joints for upper and lower layers. The distribution of the T-shaped stones shall be uniform, and its area shall not be less than 1/5 of the entire area of the pier-wall, and the length shall be greater than 600 mm; rubble rock blocks shall be

laid with the largest surface vertical, and the bricklaying method of erecting stones at the outside and filling up the inside shall not be used; elevation levelling shall be done after every 700 mm to 1 200 mm of bricklaying, and the space between alternate staggered joints shall be greater than 80 mm.

**6.6.13** When there are no design regulations, the construction of cement-stone masonry shall be in accordance with the following requirements:

- a) All the rock material for the arch ring shall be processed by template, and numbered according to row and position. The thickness of the arch stone shall not be less than 200 mm, the width shall not be less than 300 mm, and the length shall not be less than 500 mm.
- b) The arch structure shall be set up after calculation and according to the design regulation. Only after passing inspection can bricklaying start.
- c) For the arch stone construction, the masonry work shall be carried out symmetrically from both ends. The arch stone on different lines shall be cross-staggered, and the space between alternate joints shall be no less than 100 mm. When the arch span is below 5 m, rock blocks shall be used in arch bricklaying, and the camber adjusted using the joint width. The width of the lower joint shall not be greater than 10 mm, and cement mortar strength shall not be less than M7.5. When the arch span is lower than 10 m, masonry work shall be carried out symmetrically from the arch feet, according to the full width and full thickness. When the arch span is above 10 m, construction design shall be done to define the loading arch ring order, and the construction shall follow this order.
- d) Demolition of the arch structure is allowed only when the mortar reaches the payload strength, and the arch crown back fill is already finished. The demolition time of the arch structure shall be in accordance with the regulations in 6.5.6.

**6.6.14** The squeezing-mortar method shall be used in cement-pebble masonry, that is, first spread mortar with a thickness of 30 mm to 50 mm, and then embed the pebbles near each other, squeezing the mortar. The cement mortar shall be 20 mm to 30 mm lower than the pebbles while doing pointing.

**6.6.15** The construction of rock-masonry with concrete shall be in accordance with the following requirements:

- a) The bricklaying shall be done layer by layer using the mortar-spreading method, and the surface shall be roughly flat on the same layer, and the elevation difference should be less than 20 mm to 30 mm. The stone shall be placed free standing, and the larger surface shall face downwards. Make it stable by appropriately shaking and knocking. The width of the seam between the stones shall meet the requirements in Table 37, and the stone surfaces shall not be in contact.

- b) The laying of the bed mortar and the concrete filling in vertical seams shall be uniform, full and dense, and the mortar in the seams shall not be kept suspended by large aggregate. The concrete shall be mechanically-vibrated, and the distance between adjacent vibration points shall be no greater than 1.5 times the radius of the vibrating action.
- c) On the same bricklaying layer, adjacent stones shall be laid with staggered joints, and there shall be no sequential seam along the flow direction. For stones laid above each other on adjacent layers, staggered joints are also required to avoid vertical sequential seams. T-shaped stones could be placed vertically at certain intervals.

Table 37 The width of concrete cement-pebble masonry joint

Unit: mm

Type			Pier/wall/dam			Arch ring
			Coarse rock	Rock block	Rubble	Coarse rock
Concrete masonry	Horizontal seam	level 1 gradation	40~60	40~60	40~60	40
		Level 2 gradation	80~100	80~100	80~100	80
	Vertical seam	Level 1 gradation	60~80	60~90	60~100	50
		Level 2 gradation	80~100	80~100	80~100	70

6.6.16 Dry stone construction shall be in accordance with the following requirements:

- a) For dry stone projects with a frame, the frame should be constructed first, and masonry done afterwards.
- b) The construction of dry stone projects shall meet the following requirements:
- 1) The masonry seam shall be tight, and the bottom shall be stably padded and completely filled up, and shall not be empty.
  - 2) Winged edge stones and flying edge stones shall not be used.
  - 3) Vertical masonry method shall be used, and overlapping or plugging is not allowed; the thickness of the thinnest side of the aggregate shall be no less than 150 mm.
- c) When laying freestone cushions on large area sloped surfaces, the laying shall be done by layer from the bottom up, and rise by section with the raising of the masonry surface.

6.6.17 The cement mortar pointing for cement-stone masonry shall be in accordance with the following requirements:

- a) The pointing mortar used for seepage control shall be mixed independently, and shall not be

used together with bricklaying mortar. Mortar which has exceeded the initial setting time shall not be used.

- b) The cement should be ordinary Portland cement; the sand aggregate should be fine sand; the cement-sand ratio can be 1 : 1.0 to 1 : 2.0.
- c) Joint-cleaning should be carried out 24 hrs after bricklaying, and the width of the joint shall be no less than the width of the seam, and the depth of the joint shall be no less than twice the width (the depth of a horizontal joint should be no less than 40 mm, the depth of a vertical joint no less than 50 mm). The joint shall be washed out before pointing, with no ash or water left, and the joint surface shall be kept moist.
- d) Fill in the joint with the mixed mortar and compact several times until flush with the outside surface, and then trowel. The pointing surface shall be kept moist for 21 days.

**6.6.18** The bricklaying of concrete precast blocks shall meet the following requirements:

- a) The precast block size and the concrete strength shall meet design requirements:
- b) While bricklaying, T-shaped and masonry blocks placed in sequence shall be arranged according to design requirements; the joints shall be upright or be parallel to the ground, and the space between upper and lower joints shall be no less than 100 mm, and there shall not be vertical joints above or below the T-shaped stones;
- c) The joints shall be completely filled up with mortar, and the width of horizontal joints shall be no greater than 15 mm; the width of vertical joints shall be no greater than 20 mm.

**6.6.19** Masonry construction in winter, summer and on rainy days shall be in accordance with the following requirements:

- a) When the minimum air temperature is between 0 °C to 5 °C, attention shall be paid to surface protection in the masonry work; when the minimum air temperature is below 0 °C, the masonry work shall be stopped; during the curing period, heat insulation measures shall be taken for exposed masonry surfaces.
- b) For important masonry of large volume, when the maximum air temperature exceeds 30 °C, the masonry work shall be stopped. The masonry conservation shall be enhanced for construction in the summer, and the exposed surfaces shall be kept moist during the curing period, and shall be covered with straw bags or such things to prevent them from being exposed to the sun.
- c) Construction in rainy days shall meet the following requirements:

- 1) For a placement section without a canopy, the water-cement ratio shall be appropriately reduced for bricklaying in light rain, and accumulated water shall be removed in a timely way, and surface protection shall be done properly.
- 2) For a placement section without a canopy, when there is heavy rain or a rainstorm, the construction shall be stopped immediately, and the surface shall be appropriately protected. Remove the accumulated water first after the rain and deal in a timely way with parts scoured by rain. If initial setting is not yet finished for surface mortar or concrete, cement mortar shall be added to continue the bricklaying, otherwise it shall be treated as a construction joint.
- 3) Masonry and concrete for parts that are anti-abrasive or require plaster shall not be constructed in rainy days.

**6.6.20** The masonry quality shall meet the following requirements:

- a) Quality tests for cementing material shall be performed in accordance with the regulations in 6.6.9.
- b) The allowable deviation of masonry size and location shall be in accordance with the regulations in Table 36.
- c) The mortar for filling up the joints shall be dense, and the joint width shall be in accordance with the regulations in Table 35.

## **6.7 Pre-casting and assembly of concrete components**

**6.7.1** Pre-casting of components shall meet the following requirements:

- a) The site for component pre-casting and stacking shall be smooth and solid, and it shall be noted that the drainage is unimpeded. Any settlement or distortion of the foundation shall be prevented, and there shall be a standard to follow if earth form pre-casting is adopted; the surface shall be specially treated, and water shall be prevented from wetting the earth form, to avoid any earth settlement that may result in distortion and cracking of the formwork.
- b) The location of the site for component pre-casting shall be appropriately arranged according to the material route, operation sequence, storage area and the route for hoisting and transportation, and shall avoid unreasonable transportation of the material and components as well as mutual interference among the working processes. A centralized area for precast production should be set up to optimize on-site facilities and improve quality. To save the area for pre-casting, the overlapping method is commonly adopted. The isolation material between layers of the overlap-

ping precast components may be materials with small binding power, such as plastic cloth, asphaltic felt, and waste engine oil.

- c) The area for heavy component pre-casting shall be arranged, in priority, for convenience of transportation and hoisting. For large size components which are difficult to turn, the pouring direction shall be taken note of when choosing the location of the area. Vertical pre-casting should be used for long-span ribbed arches.
- d) The flying ring or retaining ring of precast components is commonly made of HPB300 grade steel, and cold drawn steel shall not be used; tensile force in homogeneity should be considered for a multi-flying ring. The anchorage length of the flying ring in concrete shall not be less than  $30d$  ( $d$ —the diameter of the flying ring reinforcement bar).
- e) The pouring of precast components shall comply with the following requirements:
  - 1) The number and location of the embedded elements shall be checked before pouring.
  - 2) For each component, the pouring shall be finished at a time, with no interruption, and shall be mechanically compacted.
  - 3) The exposed surface of the component shall be flat, smooth and without honeycomb and scale.
  - 4) When the overlapping method is adopted in pre-casting, pouring of upper components shall not be done until the concrete strength of the lower components reaches 5 MPa, and there shall be isolation measures between the layers.
  - 5) After component pouring, information on the type, concrete strength, precast date and upside/underside shall be labelled and the location of lifting points shall be marked for components without flying rings.
- f) For small size modular components, dry concrete may be used. Finishing work shall be done in time after knockout, and there shall not be any defects such as missing edges, and twisting or cracking in the component.
- g) Quality tests for precast component concrete shall follow the regulations in 6.5; besides, for important components, loading tests shall be performed when necessary.
- h) The allowable deviation of precast components shall be in accordance with the regulations in Table 38, when there is no design stipulation.



Table 38 Allowable deviation for precast component

Unit: mm

Items	Sectional dimension				Lateral bending	Diagonal	Surface flatness	Pre-formed hole	Preformed tunnel	Embedded elements		
	Length	Width	Height	Thickness						Centre line displacement	Bolt location	Exposed length of bolt
Board	+ 10 - 5	± 5	± 5	+ 4 - 2	$L/1\ 000$ $\geq 20$	10	5	5	15	10	5	+ 10 - 5
Steel frame/ truss/bent	± 10	± 5	± 5		$L/1\ 000$ $\geq 20$	—	—					
Pillar/ block	+ 5 - 10	± 5	± 5		$L/750$ $\geq 20$	—	—					
Beam	+ 10 - 5	± 5	± 5		$L/750$ $\geq 20$	—	—					
U-type/ box-type/ shell	± 5	± 5	± 5	+ 4 - 2	$L/1\ 000$ $\geq 20$	10	5					

6.7.2 Component moving and stacking shall meet the following requirements:

- a) The concrete strength shall not be less than 70% of its design strength.
- b) When moving a long component, the prying height on one end may not be larger than 2 m. Loosening before prying, and padding while prying, is used to prevent the component from cracking.
- c) The component moving method and bracing location of the lifting points shall be in accordance with the stress condition of the component to avoid damage.
- d) Component stacking shall be in accordance with the following requirements:
  - 1) The stacking area shall be flat and tamped, and have drainage measures.
  - 2) Components shall be stacked according to hoisting order, along the direction with higher stiffness.
  - 3) For overlapping components, the labels shall be exposed, and the stacking height shall be decided according to component strength, bearing capacity of the ground, cushion block strength and the stack stability. The locations of the cushion blocks on each layer shall be consistent and the cushion block on upper and lower layers shall be aligned.
  - 4) The hoisting sequence shall be considered in component stacking.

6.7.3 The hoisting of concrete precast components shall meet the following requirements:

- a) The hoisting method shall be optimally selected after comprehensive consideration, according to project scale, topography, equipment condition, technical level and economic rationality.
- b) Before hoisting, a plan for what measures to use shall be made according to the hoisting part, component length, weight and transportation road, as well as hoisting equipment.
- c) Before hoisting, systematic inspection shall be done on the carrying capacity of the hoisting equipment, tools and instruments (lifting test with load); the shape of the components shall be re-examined, and the crossbar centre line shall be labelled; support structures shall also be checked, and centre line and elevations shall be labelled.
- d) Cable-hoisting is usually adopted in hydraulic and hydro-power engineering construction without supports. Ground anchors, towers, main ropes and pulling cable hoisting equipment shall be calculated and confirmed, and the safety coefficient shall be in accordance with the regulations in Table 39.

Table 39 Safety coefficient table

Safety coefficient	Ground anchor			Main rope	Pulling/lifting rope
	Pull-out resistance	Overturning resistance	Sliding resistance		
K	≥2	≥1.5	≥1.3	≥3~4	≥5~6

- e) The concrete strength of the supporting structure for component hoisting shall not be less than 70% of the design strength.
- f) Component lifting shall be in accordance with the following requirements:
  - 1) Components shall be hoisted according to the labelled lifting point locations or embedded lifting rings.
  - 2) The angle made by the lifting rope and component shall not be less than 45°.
  - 3) Component hoisting shall be steady, and be accurate in placing in the right position.
- g) The hoisting of mould shells or masonry precast components shall be in accordance with the following requirements:
  - 1) The contact surfaces between components of different layers shall be roughened and washed out.

- 2) The width of the joint between different component layers shall be 20 mm to 30 mm, and shall be densely filled up using cement mortar with a strength no lower than the component's.
  - 3) For the installation and bricklaying of components for layers 1 to 3, the concrete shall be poured in a timely way.
  - 4) The contact surfaces of the concrete on different layers shall be treated as construction joints.
- h) The hoisting of rigid frame components shall meet the following requirements:
- 1) The horizontal location and bottom elevation of the cup-shaped pit of the component for embedding and inserting shall meet the design requirements. The horizontal-vertical axis shall be labelled on the mouth of the foundation cup, and the bottom elevation shall be 20 mm to 50 mm lower than the design elevation, to leave room for adjusting to the length error that is unavoidable for precast components.
  - 2) A gap width of no less than 30 mm shall be left between the wall of the cup-shaped pit groove and the pillar foot component, to adjust the location and for the pouring of second-stage cement mortar; if second-stage concrete is poured, the width of the gap to be left shall be no less than 60 mm.
  - 3) The cup-shaped pit of the component for embedding and inserting shall be roughened and washed out.
  - 4) The component shall be firmly supported in time after positioning, after which unhooking is allowed.
- i) The hoisting of thin shell groove bodies shall meet the following requirements:
- 1) The top surface elevation of the support shall be measured and adjusted, and the horizontal-vertical centre line shall be labelled.
  - 2) The groove bottom elevation and horizontal location shall be measured and corrections made.
  - 3) The joint gap shall meet the installation requirement of the design water-blocking material, and the minimum gap shall not be less than 20 mm.
- j) The hoisting of arch precast components shall meet the following requirements:
- 1) Before hoisting, the net span, spring line location and elevation and skewback inclined plane

shall be checked, and the location of the spring line and arch axial line shall be labelled on the skewback.

- 2) Check the chord length and joint angle of the component, and set up a scale on the arch block.
  - 3) When the arch block of the end section is hoisted to the installation position, the horizontal and axial line locations shall be checked. The displacement of the centre line at the end shall not be more than 30 mm, and the elevation shall be 20 mm to 30 mm higher than design elevation. Then, the arch block is fixed using pier buttons or suspended buttons, and secured with horizontally blowing air flow.
  - 4) The arch rib joints shall be filled up using high polymer chemistry adhesives with high adhesive power, high stability and low shrinkage, such as epoxy resin cement mortar. The formula shall be correctly mastered, the batching temperature shall be strictly controlled (no higher than 30 °C), and the component joint shall be dry, waterless and clean.
- k) The component and the exposed main bar shall be firmly welded, and damage to the concrete by high temperature welding shall be prevented.
- l) The connector and joint of precast components shall be filled by concrete or mortar with strength no lower than the design strength of the component, and an appropriate amount of quick-hardening cement or expansive cement can be mixed in.
- m) The allowable deviation for component installation shall be in accordance with the regulations in Table 40.
- n) The following preparatory work shall be done before installing (hoisting):
- 1) The hoisting program shall be approved after examination and the technical explanation is finished.
  - 2) All kinds of hoisting workers are ready, the division of work is clear, and special types of work such as lifting and signalling shall use licensed technicians.
  - 3) Lifting equipment shall be checked out by the department concerned, and records shall be kept at the local safety supervision department when necessary.
  - 4) All the safety measures are implemented.
  - 5) Unified command, obeying of orders and responsibilities assigned to every department shall be followed during hoisting.

Table 40 Allowable deviation for component installation

Unit: mm

Items		Allowable deviation	
Cup-shaped foundation	Location of centre line to axis line	10	
	Cup bottom installation elevation	0, - 10	
Pillar ( $H$ is the height of pillar)	Location of centre line to axis line	5	
	Perpendicularity	$\leq 5$ m	5
		$> 5, < 10$	10
		$\geq 10$	$H/1\ 000, \leq 20$
	Upper surface of corbel and pile top elevation	$\leq 5$ m	0, - 5
$> 5$ m		0, - 8	
Beam or crane beam	Location of centre line to axis line	5	
	Beam upper surface elevation	0, - 5	
Wallboard	Location of centre line to axis line	3	
	Perpendicularity	$\leq 5$ m	3
		$> 5$ m	5
	Component surface deviation between adjacent floor	5	
Arch rib	Location of centre line to axis line	10	
	Joint point and arch crown elevation	30	
	Height deviation of two symmetrical joint points	20	
Aqueduct body	Axial deviation of plane position	5	
	Span deviation	15	
	Elevation deviation of two adjacent aqueduct body base-boards	10	

## 7 Construction of hydraulic structures

### 7.1 Rolled earth-rock dams

7.1.1 Treatment of the dam base and slope shall meet the following requirements:

- a) For treatment of the dam base, refer to the requirements of 6.3.
- b) Treatment of the dam base and slope shall meet the following requirements:
  - 1) It is advisable to excavate and clean the abutment bank slope in top to bottom order. When the lower part of the bank slope is excavated, this shall be demonstrated to propose reliable safety assurance measures.

- 2) The dam foundation shall be cleaned, cleared, and treated according to design requirements.
  - 3) Excavation and clean-up of the dam abutment and slope shall be completed before filling. Clean-up and filling should not be done at the same time.
  - 4) When the dam base, slope and bedding foundation are being cleaned up, all the materials shall be cleaned up entirely, including trees, grass, roots, riprap, tombs and any other buildings. Treatment of wells, springs and caves shall be done properly at the same time. Slope joints, rather than reverse slope joints or step joints, shall be adopted for impervious bodies or dam bodies which are joined with rock foundations and batholiths.
  - 5) The method of pre-forming a protective layer or grouting cement mortar shall be used to protect the dam base which is easily weathered and cannot be filled at once after cleaning-up.
  - 6) Impervious grouting shall be coordinated with the impounding process of the reservoir.
- c) Construction of the bedding shall meet the following requirements:
- 1) If a block of natural soil is used as bedding, it is necessary to find out whether there is a pervious bed. The block of soil which has been chosen as the natural bedding shall not be destroyed.
  - 2) The base of man-made bedding shall be cleaned-up, flattened and compacted according to the design requirements. A filter layer shall be properly made for the gravel foundation and all passages reaching through the upper and lower reaches shall be blocked off.
  - 3) Surface protection shall be done over time after the construction of man-made and natural bedding.
- d) Only after the treatment of the dam base and slope and other concealed works have all been qualified and accepted can the filling of the dam body be carried out.

7.1.2 The following preparatory work shall be completed before filling:

- a) Investigation and control of termites
- 1) In warm and rainy areas, measures shall be taken to control termite damage and prevent termites from endangering the safe operation of small and medium-sized earth-rock dams.
  - 2) When the slope of the dam base is being excavated, professionals shall be involved to find out whether there is any hint of termites such as dirt lines, dirt covers and termite tracks.

- 3) Carry out measures to control termites, such as setting up toxic soil ditches, spraying yeast and placing poison baits.
- b) Review of borrow areas shall meet the following requirements:
- 1) A review of borrow areas shall contain the following:
    - Thickness of covering layer or peeling layer, geological damage of material bed, and interlayer distribution.
    - Dam material distribution, exploitation, processing, and transportation conditions.
    - Relationship between hydrogeological conditions of the borrow areas and the water level in flood season.
    - Exploitation scope and occupied area of borrow areas, quantity of abandoned material, available layer thickness and available reserves.
    - Physical and mechanical properties and compaction characteristics of dam materials.
    - Investigation and analysis of geological mishaps and environmental problems in the borrow areas.
  - 2) When a borrow area has been reviewed, a review report of the borrow area shall be submitted containing topographical maps of the borrow area, geological profiles, plan of test pits or boreholes, test analysis results, the calculation results for the available exploitation area and available quantity, description of all usable materials, treatment methods for unsuitable materials, exploitation and transportation conditions.
- c) Planning of a borrow area shall meet the following requirements:
- 1) General rule; no occupation or less occupation of cultivated land, make use of borrow areas in the reservoir inundation area first. Take full advantage of excavation materials from construction. Use floodplain materials in the dry season. Use upstream and downstream borrow areas properly to make the best use of materials. Fully consider conditions for mechanical work to achieve the most efficient use of machinery.
  - 2) Proportion of planned borrow area to dam filling quantity should be 2.0 to 2.5 for soil, 1.5 to 2.0 for sand-gravel material, 2.0 to 2.5 for underwater sand-gravel material, 1.2 to 1.5 for stones and should be no less than 3.0 for natural filter material.
  - 3) Planning of soil borrow areas; make use of homogeneous soil borrow areas with proper water content first; use borrow areas with higher water content in the dry season, and lower

water content in the rainy season.

- 4) Planning of sand and gravel borrow areas: Filling materials, screening materials and filter materials shall be fully planned and a proper quarrying schedule shall be prepared as well. Proper mining equipment and methods shall be chosen for mixed mining and mining above and under water respectively.
  - 5) Planning of rock borrow areas: borrow areas with unitary lithologic features, thin overburden, good mining and transportation conditions and less construction disturbance shall be mined first.
  - 6) Necessary processing and stockpile areas shall be taken into consideration in borrow area planning.
- d) Schedule of construction tests shall meet the following requirements:
- 1) Construction tests should be conducted on testing grounds outside the dam area.
  - 2) Field construction testing shall be carried out before construction so as to determine construction technology, optimize equipment configuration, process flow, and construction parameters. The construction test shall include: re-examining the relevant technical indexes and construction technology and construction parameters determined in design; proposing technical requirements and inspection methods for quality control; and formulating relevant construction technical measures.
- e) Mining of rock fill materials shall meet the following requirements:
- 1) Methods of mining soil materials: the vertical mining method can be applied in borrow areas which lie on hills, in borrow areas with a thick soil layer, different soil properties and uneven water content, and in borrow areas with low soil water content. The horizontal mining method can be used in plain and open borrow areas with a thick soil layer and in borrow areas with high soil water content.
  - 2) Methods of mining sand and gravel materials: Over water, bulldozers can be used to collect materials horizontally and then loaders can be used to dig and hold the materials. Under water, backhoes can be used to mine the materials vertically. Backhoes or draglines can be used to mine the materials under mixed conditions.
  - 3) The drilling and blasting method or chamber blasting method should be adopted when quarrying rock materials. Under both of these two methods, bench mining should be adopted and blasting parameters shall be selected by tests.
  - 4) When the borrow area has been mined out, the fields shall be flattened to farmland. Crag



treatment, soil and water conservation and environmental protection shall also be properly done.

- f) Transportation of dam materials shall meet the following requirements:
- 1) When choosing transport methods, these factors shall be taken into consideration: the roads shall have access to the dam crest directly, and reduce links in trans-shipment; excavating, loading, transporting and unloading shall be closely coordinated to achieve the most efficient use of machinery; transportation shall match the properties of the dam material and fill intensity; choose as few types of machinery as possible for management and maintenance convenience.
  - 2) The following factors shall be taken into consideration for transport route planning: arrangements for transportation in different stages shall be coordinated with the filling of the dam. The rationality of accessing the dam crest through the dam slope shall be fully considered. Make full use of the landform and arrange for heavier trucks to go downhill. Construction roads should be combined with permanent roads as much as possible. Width, gradient, curve and line of sight distance of roads shall meet the driving requirements and avoid level crossings as much as possible; strengthen road maintenance.

#### 7.1.3 Construction of soil anti-seepage bodies shall meet the following requirements:

- a) Construction of soil anti-seepage bodies shall comply not only with the requirements stipulated in 6.1.4, but also the following requirements:
- 1) When vehicles are used to transport and unload materials at the dam crest, the method of bank-off advancing shall be adopted to unload the materials.
  - 2) Anti-seepage bodies can be filled without dividing into different areas or sections and should rise completely and remain horizontal. They shall be filled at the same time as upstream and downstream filter layers, transition zones and parts of the dam shell material. Anti-seepage bodies shall be rolled across the joints.
- b) When the anti-seepage body is combined with the rock foundation, bank slope and concrete, it shall be constructed according to the following requirements:
- 1) Remove soil, dirt, dust and loose rock on the surface.
  - 2) Water the contact surface to keep it moist and then spread thick mud while filling and compacting.
  - 3) Filling of an anti-seepage body in the range of 0.5 m to 1 m to the dam base, 1.5 m to a bank slope joint, 0.5 m to a concrete toothed wall, or in the corner, shall be filled by thin layers

and compacted by light machines. Filling on both sides of a toothed wall shall rise equally.

- c) Construction of a weathered material anti-seepage body shall meet the following requirements:
  - 1) Weathered material shall be mined from borrow areas stipulated by design, and the material quality shall meet design requirements.
  - 2) A cohesive material layer of 0.5 m, whose compacted dry density shall meet the design requirements, shall be constructed between the weathered material and rock base (foundation or bank slope).
  - 3) Weathered material shall be compacted by convex vibrating rollers.
  - 4) Construction indices of weathered material can be decided with reference to the following empirical parameters, and adjusted through tests: maximum grain size shall be less than 150 mm; water content shall be between 8% and 12%; thickness of layer shall be between 300 mm and 400 mm; the number of times of rolling shall be between 10 and 14.
- d) If an anti-seepage body of soil material is built during the rainy season, attention shall be paid to the following items:
  - 1) Loose soil layers on the surface shall be compacted with flat rollers to keep them flat and smooth, and the surface shall tilt in the upstream direction to drain off water and prevent rain infiltration.
  - 2) If the filling area is narrow, plastic film or canvas can be used to cover the surface.
  - 3) Vehicles or pedestrians shall not be permitted to pass during and after rain.
  - 4) Construction machinery shall be placed outside the filling area.

**7.1.4** The construction of an impervious body of reinforced concrete panel shall meet the following requirements:

- a) When the dam height is less than 100 m, the panel concrete shall be poured all at once; when the dam height is greater than or equal to 100 m, the panel can be poured in stages according to the construction arrangement or the need of water storage in advance. Pouring joints in stages shall be treated according to construction joints. If there is a design requirement, it shall be handled according to the design requirement.
- b) The panel shall be built after meeting the design requirements for pre-settlement period and monthly settlement rate. When the panel is built in stages, the top of the panel shall be filled to a certain height in the early stage. When the dam height is over 100 m, the overfilling height

above the top of the stage panel shall not be less than 10 m.

- c) Before the panel is built, the grid of the bedding layer slope surface shall be measured and set out. The deviation between the outer sideline and the design sideline shall meet the design requirements. Before concrete pouring, slope protection (including extruded side wall) shall be checked and void and partial damage to slope shall be handled in time.
- d) Trackless sliding form and sequence placement shall be used for panel concrete pouring, and the initial triangular block shall be poured together with the main panel.
- e) The following principles shall be followed in designing sliding formwork:
  - 1) Adapt to the width of panel strip and flatness of sliding formwork.
  - 2) Have sufficient strength and stiffness.
  - 3) Have enough counterweight.
  - 4) Meet the needs of construction vibration and pressure surface.
  - 5) Installation, operation and disassembly are convenient and flexible.
  - 6) Safety measures shall be taken. Braking devices shall be installed on the sliding formwork and the ground anchor shall be safe and reliable when the traction is via winch.
- f) The width, thickness and smoothness of a slope surface of cement mortar cushion under vertical joints shall meet the design requirements.
- g) The panel steel bars shall be bonded, welded or mechanically connected on site, or adopt the method of full assembly of prefabricated steel mesh on-site.
- h) The side formwork of the cast panel can be composite steel formwork or wood formwork with a protective angle. The height of the side formwork shall meet the need for panel thickness. The length of the blocks and the anchorage method shall be convenient for installation and disassembly on the slope surface. When the side formwork is used as the sliding formwork support structure, it shall be designed according to the force-bearing structure.
- i) Side formwork installation shall be firm and secure, the inner surface shall be flat, and the water-stop facilities shall be fixed in place, and the water-stop facilities shall not be damaged. The allowable installation deviation is as follows:
  - 1) The deviation from the design line of the joint is  $\pm 3$  mm.

- 2) Verticality is ( $\pm 3$  mm).
  - 3) The fluctuation difference within 2 m is  $\pm 5$  mm.
- j) Concrete pouring shall comply with the following regulations:
- 1) The concrete shall be uniformly distributed in the storehouse, and the thickness of each layer shall be 250 mm to 300 mm. The concrete around the water stop shall be supplemented by artificial distribution and aggregate separation shall not occur.
  - 2) After the distribution, it shall be vibrated and compacted in good time. When vibrating, the vibrator shall not touch the sliding formwork, reinforcing bar and water stopper. Vibrator shall not be placed on or near sliding formwork and be inserted into the pouring layer along the sliding formwork. Vibrators shall be vibrated within the sliding formwork, the vibration spacing shall not be greater than 400 mm, the depth of the vibrator inserted into the lower concrete vertically shall be 50 mm, the diameter of the vibrator shall be no greater than 50 mm, and the diameter of the vibrator close to the side formwork shall be no greater than 30 mm. The concrete around the water stopper shall be vibrated and compacted.
  - 3) During the pouring process, the concrete adhering to the formwork and steel bars shall be removed in time. The front edge superfill concrete shall be removed before each sliding.
  - 4) For the surface of the concrete after demoulding, it shall be levelled and pressed in time. The concrete surface within 1 m on each side of the joint shall be inspected with a 2 m long ruler and the unevenness shall not exceed 5 mm.
  - 5) Each sliding distance shall not exceed 300 mm, and the interval between each sliding shall not exceed 30 min. The average sliding speed of panel pouring shall be 1.5 m/hr to 2.5 m/hr, and the maximum sliding speed shall not exceed 3.5 m/hr.
- k) When the panel is poured in stages, the concrete surface of the construction joint shall be set at a thickness of not less than 1/2 of the section in the direction of the normal line of the panel, and other parts may be set in the horizontal direction. The steel bars of the first pouring panel shall pass through the construction joints, and the length of the steel bars exposing the construction joints shall not be less than the anchorage length.

**7.1.5 Construction of geo-synthetic anti-seepage bodies shall meet the following requirements:**

- a) Material quality, connection, transportation and safekeeping of geo-synthetics shall meet the following requirements:
  - 1) Choose geo-synthetics according to the design requirements. The geo-synthetics shall meet the requirements of the relevant standards.

- 2) Main physical and mechanical indices of the geo-synthetics shall be retested when transported to the construction site.
  - 3) Adhesive tests of geo-synthetics shall be conducted, and meet the following requirements:
    - Indoor and outdoor tests shall be conducted under different temperature conditions at the construction site.
    - Adhesive tests where curing agents are added to binders shall be conducted in winter in order to reduce the curing time.
    - Curing time shall meet the requirements for construction intensity.
    - When binders are changed, adhesive tests shall be conducted again.
    - When thermoplastic materials are chosen for geomembranes, either the method of hot melt adhesion or impulse heating soldering devices can be adopted for hot melt joints.
    - Joint connection methods can be adopted to connect the geo-synthetic when it serves as a filter layer.
  - 4) Geo-synthetics shall be properly transported and safely stored. Geo-synthetics shall not be piled up in the open air because sunshine will accelerate the aging of the materials. Geo-synthetics shall be properly kept in a dry environment. The ratio between the surplus area and the laying area shall be 25% to 100%.
  - 5) Check the surface of geo-synthetics carefully. If there is any breakage, the material shall be repaired or changed. Materials with serious breakage shall not be used. Man-made damage shall also be avoided during construction.
- b) Laying of geomembranes and composite geomembranes shall meet the following requirements:
- 1) Preparatory work shall be done before construction; geomembranes and geotextiles shall be cleaned, tailored, and well-folded. Bonding platforms shall be built up on the construction site. Bonding of materials shall be carried out according to the actual situation. During bonding, ensure that the joints are wide enough and are kept smooth.
  - 2) Flatten the base: The base shall be compacted to be smooth and flattened to the shape or slope required by the design. There shall be no water, grass, gravel or objects with edges left on the base. A protective layer shall be built before laying the geomembranes to prevent them from being pierced.
  - 3) Position them correctly. Lay the material from bottom to top and leave enough overlapping

area in the joints and enough area for the material to relax.

- 4) The width of bonding joints shall meet the design requirements. However, the width shall be no less than 80 mm. Binders shall be mixed evenly and spread evenly. There shall be no sundries such as gravel and soil particles in the joints. The joints shall be pressed at once and left to cool and dry naturally. Binders can be warmed to meet the requirements for construction progress if the weather is too cold but the binder temperature shall be no higher than 60 °C.
- 5) When geomembranes of the core wall are laid vertically, they shall be laid in a zigzag pattern. If longitudinal expansion joints are made in the direction of the dam axis as required by the design, it is recommended to use composite geomembranes to reduce the friction of the layers when the joints have been pulled out. If a simplex geomembrane is used, protective measures shall be adopted on both sides of the geomembrane, such as adding a transition layer of fine particles or geotextiles. Vibrating rollers cannot be used in the backfilling area which is in the range of 500 mm or 1 000 mm from both sides of the core wall, whereas frog rammers can be used in this area. If there is clay on one side of the geomembrane, the retaining-plank method can be adopted in the construction. The offset between the actual axis and the design axis of the geomembrane shall be no more than 100 mm.
- 6) When the hot melt adhesion method is adopted, soldering shall meet the following requirements:
  - The welding machine working temperature and speed is adjusted and controlled according to temperature and material properties at any time. The welding machine working temperature shall be 180 °C to 200 °C.
  - PE geomembrane at the weld joint shall be welded into an integral whole and there must be no cold joint, weld skip or excessive welding.
  - When cold joint or weld skip occurs, the weld joint must be cut, and the damaged parts must be repaired by hot melt extruder using base metal with a diameter more than twice the damaged part diameter.
  - Width of double weld seams should be 2 mm × 10 mm.
  - The malposed size between transverse welds shall be greater than or equal to 500 mm.
  - The T-shaped joint shall be repaired with the base metal and the size of the patch can be 300 mm × 300 mm. The right angles of the patch shall be rounded off.
  - In welding, it is necessary to cut off the damaged PE geomembrane in time and weld it firmly by hot-melt extrusion.

- The two-layer PE geomembrane must be flattened and relaxed.
- c) The laying of composite geotechnical materials on the dam slope and sloping core shall meet the following requirements:
- 1) When laying materials on the dam slope, the coiled materials should be rolled out and laid from top to bottom. Treatment of joints shall be done properly.
  - 2) Workers shall wear soft shoes when laying geomembranes. The materials shall be properly covered, and meet the following requirements:
    - Geomembranes on dam slopes can be protected by concrete panels or rock revetment.
    - Geomembranes on the reservoir bed and bottom of the pool shall be covered by sand gravel or gravel, with a covering depth of no less than 300 mm to 400 mm.
    - In cold regions, geomembranes shall be quickly covered over to prevent frost damage.
    - In regions with a fluctuating water level, the depth of the protection layer shall be thicker, and equal to the depth of the frozen ground.
    - The covering material shall be selected from coarse aggregate such as crushed gravel and cobble gravel.
    - On the steeper slopes of the dam and reservoir, the protective layer should not be made of clay.
- d) The peripheral connection of geomembranes shall meet the following requirements:
- 1) Geomembranes shall be laid on the surrounding impervious layers.
  - 2) For the connection between geomembranes and the cut off wall below, if the design requires that the geomembranes be connected to the concrete cut off wall below, geomembranes shall be directly embedded, and the embedded depth shall be no less than 100 mm to 300 mm. The geomembranes shall be folded into the shape “弓”. In the embedded places, concrete placement can be done as the second stage concrete. When geomembranes are directly connected to the rock foundation of the dam, the upper weathered layer shall be cleaned up, and geomembranes shall go 300 mm to 500 mm deep into the integrated rock foundation and then be embedded by concrete. When the foundation is a clay toothed groove, geomembranes shall be folded zigzag like “弓”, and shall be manually tamped layer by layer.
  - 3) For the connection between geomembranes and the bank slope, if there are no design re-

quirements, geomembranes can be embedded in concrete thorn walls or by going deep into the impervious rock foundation.

- e) Protection Works: when geomembranes are used for anti-seepage on sloping walls, a protective layer shall be laid on the finished geomembranes.
  - 1) The soil protection layer shall be laid from top to bottom. The thickness and density of the layer shall be built according to design requirements.
  - 2) If the protective layer consists of hard material, such as concrete, flagstone and dimension stone, the foundation shall be carefully treated to control the distortion and prevent the geomembranes from sliding and causing tearing cracks. Furthermore, the peripheral laying and pressure on the top part shall be coordinated during construction to ensure the comprehensive nature of the laying work. If the protective layer is made by spraying the concrete, consistent concrete thickness shall be ensured.
- f) The construction quality inspection shall comply with the following requirements:
  - 1) Set up a quality inspection system and raw materials, materials tests, preparation and use of binder, joints, planeness of laid surface and peripheral connections shall be inspected regularly by specially-assigned persons.
  - 2) Appearance inspection shall be done each time the filler on both sides of the geomembranes rises by one layer. Any abnormalities, if present, shall be handled in good time. Every time the dam height rises 2 m to 4 m, test pits shall be dug along both sides of the geomembranes to inspect the planeness, folds, bursting, broken lines, leaks, joint cracks and so on. If the situation is serious, remedial measures shall be taken in a timely manner. The depth of the test pit shall be 1 m to 1.5 m, and there no fewer than 2 to 4 test pits shall be arranged along the dam line.
  - 3) Construction notes shall be properly taken and the data on the construction quality inspection, temperature, various raw materials tests and quality accident reports shall be properly kept.
  - 4) Sub-projects such as the laying of geomembranes and peripheral connections shall be checked and accepted at an intermediate stage of the construction.

**7.1.6** The construction of the dam shell material shall comply with the following requirements:

- a) When a motorised vehicle is chosen to transport materials up to the dam, the sand gravel and rockfill material shall be unloaded by the method of laying in reverse direction or combined method (laying in reverse direction first and then advancing).



- b) After the dam shell material filling, sufficient water shall be sprinkled and the amount of sprinkling water shall be about 15% to 25% for sand gravel, and 12% to 30% for rockfill material.
- c) The paving materials shall be level, and their thickness shall be strictly controlled.
- d) The maximum diameter of rock blocks shall be less than 2/3 of the layer thickness.
- e) The dam shell material shall be compacted by vibrating rollers. The compaction time shall be determined by corresponding tests.
- f) The actual slope filling shall be 300 mm to 500 mm greater than the design value. For convenience in cutting the slope, fine materials should be filled to within a range of 300 mm to 500 mm close to the slope.
- g) On the sides or corners where a vibrating roller cannot reach, fine material 1 m to 1.5 m wide should be filled. A tamping plate is used to compact, or a thin filling layer is used and then compacted by a frog rammer. The dry density compaction at the sides and corners should not be less than the design value of 96%.

7.1.7 Inverted filter layer construction shall comply with 7.1.5 and shall meet the following requirements:

- a) The sand material gradation, silt content and fineness modulus shall meet design requirements.
- b) The material for inverted filter layers shall be transported by loaders and manually flattened. After sprinkling sufficient water, a vibratory plate compactor or plate vibrator is used for compaction.

7.1.8 The construction of cushion material and transition material in the faceplate anti-seepage body shall meet the following requirements:

- a) The paving width, gradation, uniformity coefficient and permeability coefficient of the cushion material and transitional material shall meet design requirements.
- b) The thickness shall be half that of the rockfill materials and compacted by traction type vibration rollers. The edge joint between every two filling layers and the dam shell material shall be compacted once. A 300 mm to 500 mm surplus margin shall be maintained at the slope. Every 10 m to 15 m, the slope surface shall be flattened and compacted. The flat slope surface shall be 50 mm to 100 mm higher than the design line. The slope surface should be compacted by a traction type vibration roller of 80 kN to 100 kN, with static rolling first followed by vibratory rolling. The topside needs to be vibrated while the downside does not. The compaction time shall be determined by corresponding tests.

- c) Cement mortar with a thickness of 50 mm to 80 mm and a strength of 5.0 MPa to 7.0 MPa shall be paved on the upstream slope to protect it. The unevenness shall be less than 50 mm.
- d) The cement mortar shall be tightly combined with the asphalt material which is under the cutoff copper plate in the area around the block. No part should be omitted during laying.
- e) Attention shall be paid to protecting the cement mortar protection surface, and to curing it for 15 days by sprinkling water.
- f) Some new technologies, such as rolled mortar slope protection, cation emulsified asphalt slope protection and crushing concrete type of side walls shall be adopted in the construction of the faceplate anti-seepage body.

7.1.9 The drainage system and slope protection shall meet the following requirements:

- a) The drainage system shall pay attention to the following items:
  - 1) The rock materials making up the drainage system shall be hard and solid. The mechanical properties and geometric dimensioning shall meet design requirements.
  - 2) The thickness of manual filling rock shall be no less than 1 m, and the upper layer and the lower layer shall interlock without horizontally-connected cracks.
  - 3) The foundation of the drainage system inside the dam shall be compacted. The longitudinal slope of the drainage system shall meet design requirements, and the connection shall be properly soldered and an inverted filter layer shall be laid. The connection of the drainage system outside the dam shall be watertight and incorporate anti-freezing measures.
  - 4) Other drainage facilities such as a relief well and deep type drainage ditch shall meet design requirements.
- b) The upstream slope protection shall comply with the following requirements:
  - 1) The rock materials used for slope protection shall be hard and solid. The compressive strength and geometric dimensioning shall meet design requirements.
  - 2) The riprap slope protection shall be properly matched with the dam body filling, and the riprap and filling shall proceed simultaneously.
  - 3) The stone pitching shall be built vertically from bottom to top with staggered joints that shall be dense and stable. Large stones shall be sealed at the edges and the stone's surface shall be smooth.

- 4) The precast concrete blocks shall be installed from bottom to top with staggered joints. The surfaces shall be smooth with enough drain holes.
- c) For the downstream turf slope protection, grass which can take root easily, spreads around and is drought-tolerant should be chosen. The seeding distribution shall be uniform and it needs to be cared for by sprinkling water. If the soil is non-cohesive, a layer of humus shall first be laid before growing the turf.

7.1.10 Construction in the rainy season and on sub-zero temperature days shall be carried out in accordance with the following requirements.

- a) Filling during the rainy season shall meet the following requirements:
  - 1) Local hydrological and meteorological data shall be analysed to determine the construction days for various dam materials during the rainy season, the quantity of construction machinery and equipment shall be reasonably selected, and construction measures shall be worked out for the rainy season.
  - 2) According to the hydrological and meteorological forecast, the filling time shall be rationally arranged, the rainproof preparations shall be done in advance, and the opportunity to resume construction during the rainy season shall be grasped.
  - 3) It is advisable to heighten the filling of the core wall of the core wall dam and the filter materials on both sides and some of the dam shell materials on sunny days, and continue to fill the dam shell materials on rainy days, so as to keep the dam surface rising steadily.
  - 4) The filling surface of the core wall and inclined wall should be inclined to the upstream side, and the filling surface of the wide core wall and homogeneous dam shall be raised in the centre and inclined to the upstream and downstream sides.
  - 5) The filling area of the impervious body shall be properly reduced and the soil shall be levelled and compacted in good time.
  - 6) Flat but not rolled loose soil shall be quickly rolled into a smooth surface using a smooth drum vibratory roller before rainfall, and mechanical equipment on the filling surface of the impervious body shall be withdrawn and remain in the dam shell area.
  - 7) Take protection measures for the dam surface on rainy days until work resumes. Construction machinery and personnel must not pass through the impervious body and filter materials.

- 8) Impervious body surface hydrops shall be removed first to resume work after rain. If there is excessive water content in the non-compacted surface soil of the impervious body, the soil can be loosened, dried or removed; filter materials mixed and polluted by soil shall be removed. Filling cannot be done on the dam surface with accumulated water and mud.
  - 9) Construction of sand-gravel material and rockfill areas can continue on rainy days, but the polluting of materials by mud shall be prevented.
- b) Filling in negative temperature shall meet the following requirements:
- 1) Special construction measures shall be compiled and the dam materials, thermal insulation, and anti-freezing measures shall be selected according to the weather forecast.
  - 2) A 1.0 m to 2.0 m loose soil layer shall be pre-filled or other anti-freezing measures shall be taken before the dam foundation freezes. Filling may be done if there is no obvious ice interlayer and frost heave after the freeze protection measures are taken for the dam foundation.
  - 3) The open-air soil filling area shall be reduced and the soil paving, rolling, and sampling operations shall be rapid and continuous. The soil temperature during compaction shall be above  $-1\text{ }^{\circ}\text{C}$ . When the minimum temperature is below  $-10\text{ }^{\circ}\text{C}$  or below  $0\text{ }^{\circ}\text{C}$  and the wind speed is greater than 10 m/s, construction shall be stopped.
  - 4) The water content of clayey soil is not more than 90% of plasticized soil and the water content of fine aggregate with a particle size less than 5 mm in sand and gravel shall be less than 4%.
  - 5) The freeze prevention and heat preservation of compacted soil layers shall be performed appropriately to avoid soil freezing. The frozen part of the impervious body such as the homogeneous dam body, core wall, and inclined wall shall be removed. The compacted layer of gravel and rockfill can be continuously filled if the dry density after the freezing has reached the design stipulation.
  - 6) When filling is stopped, the surface of the impervious body shall be protected from freezing and removed during filling.
  - 7) No ice and snow shall be caught in the filling.
  - 8) Soil, sand, sand gravel materials, and rockfill shall not be watered. If necessary, measures such as thinning the thickness of the layer and improving the compaction capacity shall be taken to guarantee the quality.

- 9) If the construction is stopped due to snow, the snow on the dam surface shall be cleared before resuming work.

7.1.11 Construction quality control shall meet the following provisions:

- a) Quality control shall comply with this document and relevant standards and technical documents.
- b) The management of workstages and processes shall be strengthened. During construction, strictly follow the procedure that if a work process is not qualified, the following process shall not be allowed to proceed.
- c) A quality control station shall be set up in the borrow area to control the quality of the dam materials. No unqualified materials shall be transported to the dam. The quality inspection in the borrow area mainly consists of visual inspection and manual testing. Only some representative samples shall be tested. The identification items and indices shall include the following:
  - 1) For anti-seepage soil materials, the upper and lower limit of water content, the lower limit of clay content, soil property and grain size shall be inspected.
  - 2) For inverted filter materials, the gradation, silt content and weathered particle content shall be inspected.
  - 3) For transitional materials, the gradation, maximum grain size and silt content shall be inspected.
  - 4) For dam shell gravel materials, the gravel content and silt content shall be inspected.
  - 5) For rockfill materials, the maximum rock size, content less than 5 mm, and content of weathered weak particles shall be inspected.
- d) Quality control of the dam body filling shall focus on the following contents:
  - 1) For the soil anti-seepage body, the planning of the surface roughness between layers, water content, the thickness of soil layer, rolling parameters, surface smoothness, shearing failure, springy soil, less compaction or missing compaction, connections with the foundation or slope concrete, and dam slope control.
  - 2) For the inverted filter layer, the transition layer and the dam shell materials, it is mainly compaction parameters, joints and protection measures that shall be controlled. The thickness of the laid layer and the rolling time shall be checked and statistically analysed to study improved measures. The items to be checked in dam compaction and the sample items are listed in Table 41.

Table 41 The Items to be checked in dam compaction

Material type and position			Checked items	Sampling times
Anti-seepage body	Clayey soil	Corners	Dry density and water content	2~3 times/layer
		Rolling surface		1 time/100 m <sup>3</sup> ~ 200 m <sup>3</sup>
		homogeneous earth dam		1 time/200 m <sup>3</sup> ~ 500 m <sup>3</sup>
	Gravel soil	Corners	Dry density, water content and gravel content of larger than 5 mm	2~3 times/layer
Rolling surface		1 time/200 m <sup>3</sup> ~ 500 m <sup>3</sup>		
Inverted filter material			Dry density, gradation, silt content	1 time/200 m <sup>3</sup> ~ 500 m <sup>3</sup> , 1 time every layer
Transition material			Dry density, gradation	1 time/500 m <sup>3</sup> ~ 1 000 m <sup>3</sup> , 1 time every layer
Dam shell sand material			Dry density, gradation	1 time/5 000 m <sup>3</sup> ~ 10 000 m <sup>3</sup>
Dam shell gravel material			Dry density, water content, gravel content smaller than 5 mm	1 time/3 000 m <sup>3</sup> ~ 6 000 m <sup>3</sup>
Rockfill material			Dry density, gradation	1 time/10 000 m <sup>3</sup> ~ 100 000 m <sup>3</sup>
<b>NOTE</b> The testing time for gradation of rockfill material can be less than that for dry density.				

- e) Several fixed sampling positions shall be selected on the soil anti-seepage body, and representative samples are taken to do laboratory tests every 10 m along the dam height. The results can be used as reference for checking out design and engineering management.

## 7.2 Masonry dams

7.2.1 The construction of masonry dams shall comply with the following general requirements:

- a) Besides the requirements in this section, the construction of masonry dams shall also comply with the regulations in 6.6.
- b) The treatment of masonry dam foundations shall be in accordance with the regulations in 6.3.
- c) The stone-laying operation shall be based on the solidification condition of the cementing material.
  - 1) Before the initial setting of the cementing material, the laying of two layers of stones at a time is allowed.
  - 2) When the cementing material is between the initial setting and final setting, no disturbance to the masonry is allowed.

- 3) After the final setting of the masonry cementing material, if bricklaying needs to continue, the requirement for the cementing material strength and masonry surface shall be in accordance with the regulations in 6.6.10.
- d) The masonry shall be constructed by blocks according to the design stipulation. Within the same block, the bricklaying of the dam shall completely and continuously rise layer by layer. The level difference between adjacent masonry should be less than 1.5 m and shall be in the shape of steps according to the stone standard and the requirement of staggered joints for upper and lower layers.

#### 7.2.2 The surface stones and some structural details shall meet the following requirements:

- a) The stone-laying for the dam surface and body should rise at the same rate. For conditions with different rates, the level difference shall be less than 1.0 m and the joint surface shall be treated as a vertical construction joint. Flaky stone padding under the surface stone is not allowed.
- b) When the stone for the dam body is bonded to concrete, the rough surface should be used.
- c) If the dam's outer surface is a vertical plane, coarse stone should be used for the surface and the construction form should be a staggered and T-shaped. When the dam surface is a downward grade inclined plane, special shaped stones should be used. If the inclined plane can be in the form of steps, coarse stone can also be used and laid horizontally.
- d) The head curve and inverted-arch section of the spillway surface should be constructed out of special shaped stones and high-grade cement mortar. The arch crown of the gallery should be built with tappets. If coarse stone is used, the width of the joints can be adjusted to form the arch.
- e) For arch and multiple arch dams, if coarse stone is used then the arch can be formed by adjusting the width of vertical joints. However, the width difference between the two ends of one joint should be less than 10 mm for arch dams and should be less than 20 mm for multiple arch dams.
- f) The surface of settlement joints shall be kept smooth and upright.
- g) The construction of multiple arch dams shall comply with the following regulations:
  - 1) The contact surface between an arch barrel and buttress shall be treated as a construction joint.
  - 2) The stone-laying for all arch barrels shall rise up at the same rate. Under the condition of different rates, the level difference between two adjacent arch barrels shall meet the requirements for buttress stability.

- 3) When an inclined arch barrel is built, the concrete skewback with an inclined plane (which is perpendicular to the arch barrel) should be formed in advance on the bedrock. Then stones are laid on this skewback and the surface of the laid stones shall be kept perpendicular to the inclined plane of the inclined arch.
- h) The overhang construction of dam surfaces shall comply with the following regulations:
- 1) If special shaped stones are used and laid horizontally, they shall be processed and numbered one by one and then placed according to the number.
  - 2) For overhang stairs construction, the width in the protruding direction shall be less than 1/5 of the stone's width.
  - 3) For vertical overhang construction of coarse stone, the dam body stone and concrete shall be constructed in good time.

**7.2.3** The construction of concrete cut-off walls shall meet the following requirements:

- a) The anti-seepage type of masonry dam can adopt concrete-faced plates, concrete core walls, jointing with cement mortar and geotechnical diaphragms.
- b) The concrete anti-seepage body shall be embedded into the bedrock. The measures of combined light blasting, prying and digging shall be implemented for the toothed groove's excavation. Rocks within 500 mm of the design basic plane shall be pried and dug in order to avoid cracking the bedrock.
- c) The concrete anti-seepage shall be built after stone-laying. The height of the anti-seepage body shall be a little lower than the stone-laying surface.
- d) The anti-seepage body concrete shall meet the design requirements for anti-cracking, anti-permeability, anti-freezing, anti-erosion and strength performance. The requirements of concrete construction technology shall comply with the regulations in 6.5.
- e) Embedding stones in the concrete anti-seepage body is not allowed.

**7.2.4** The construction of the glacis of the spillways shall meet the following requirements:

- a) The strength of the stone materials used in the construction of the glacis of the spillways shall meet design requirements. The requirements of coarse stone shall meet the regulations in 6.6.1, and the outside surface should be embellished and processed. The plane difference should be less than 2 mm.
- b) Brickwork shall be laid with alternate joints for upper and lower layers. The construction form



shall all be staggered T-shaped (it shall not form a flat surface in line with the contact face of the dam), or partly staggered T-shaped and partly placed in line. The height difference between two adjacent planes shall be less than 5 mm. The width of joints shall be uniform and no less than 20 mm; the joint shall be completely and densely filled with mortar.

- c) The allowable deviation of glacis size and position shall meet the requirements listed in Table 36.

**7.2.5** Construction quality control shall meet the following requirements:

- a) In the construction of masonry dams, a perfect quality assurance system and a sound responsibility system shall be established.
- b) The quality control shall proceed according to relevant standards, construction drawings and technology requirements in the contracts.
- c) Quality inspection records shall be organized, analysed, summarized and filed in good time.
- d) The raw materials for masonry dams shall meet the regulations in 6.6.
- e) The quality inspection of site concrete shall meet the regulations in 7.3, and the quality inspection of mortar and masonry concrete shall meet the regulations in 6.6.

**7.2.6** Construction quality inspection of dam bodies shall meet the following requirements:

- a) The construction quality inspection of masonry bodies shall meet the regulations in 6.6.20.
- b) For the density inspection of masonry bodies, when the inspection position is lower than 1/3 of the dam height, at least one group of test pits shall be dug every 5 m to 10 m; when the position is higher than 1/3 of the dam height, the number of test pits shall be determined by joint consultation and research. The water injection method should be adopted as the preferred density testing method.
- c) The compactness of masonry bodies shall be inspected for every new layer using simple tests (such as intercalation and water filling tests).

### **7.3 Concrete dams**

**7.3.1** For concrete dams, the following preparatory work shall be completed before pouring:

- a) Working out construction planning. The content shall accommodate the requirements for flood protection during diversion, foundation treatment, metal structure installation, reservoir impoundment and power generation for each stage, according to dam type characteristics and actual site conditions. The concrete construction schedule for a dam during the first low water pe-

riod shall be taken particularly seriously. Priority shall be given to construction of parts related to diversion and flood protection, structures which are complex and which control the construction period, contact grouting whose temperature is required to be controlled, curtain grouting which requires ballasting.

- b) A concrete sandstone aggregate system, mixing system, temperature control system and transport system shall be installed and adjusted according to the requirements of 7.3.3.2 to 7.3.3.9, and then trial production shall be carried out.
- c) Excavation treatment at the dam foundation shall meet the design requirements and pass the acceptance tests.

**7.3.2** Jointing and block-formation of concrete and the pouring thickness shall meet the following requirements:

- a) Jointing and block-formation shall follow the following principles
  - 1) Jointing positions shall comply with structure layout requirements and geological conditions.
  - 2) The longitudinal jointing layout shall comply with stress requirements for the dam body section, with uniform block-formation and convenience for union-grid pouring.
  - 3) Block size shall be adapted to the pouring capacity.
  - 4) For block size, the requirements for quality and schedule as well as the economic principles shall be complied with.
- b) Both segmentation and jointing and block-formation of concrete placement shall meet the design requirements. If there is no specific design stipulation, then the distance between two adjacent transverse joints may be set at 15 m to 20 m, and for dam monoliths of the powerhouse, the distance may be extended to 20 m to 25 m; the distance for longitudinal joints may be set at 15 m to 30 m.
- c) Concrete pouring thickness shall be determined by calculation according to the allowable temperature difference. Within the range restricted by the foundation, the layer thickness should be 1 m to 2 m and 3 m to 6 m outside the foundation-restricted range. In the same block and segment, the elevations of horizontal construction joints of adjacent pouring blocks shall be staggered. If a horizontal construction joint intersects with the top arch of the gallery, it should be connected with skewback of gradient 1 : 1 to 1 : 1.5, or the distance between horizontal construction joints above the gallery and gallery top shall be no less than 1.5 m.
- d) The interval time between two adjacent upper and lower concrete layers should be controlled

from 5 days to 7 days, and the maximum value should not exceed 10 days.

- e) During construction, each dam block should be uniformly raised, the elevation difference between adjacent dam blocks should not be greater than 6 m, and the maximum value should not exceed 10 m. For special segments, steel tube burying bins for instance, if the limitation is expected to be exceeded, heat preservation measures shall be employed, such as laying mesh reinforcement on top or reinforcing heat preservation. For construction in the summer, maintenance and protective measures shall be continued until the upper layer concrete is covered.

**7.3.3** Layout of the aggregate production system shall meet the following requirements:

- a) The aggregate production system consists mainly of the borrow area and the aggregate processing plant.
  - 1) The necessary amount of aggregate materials shall be determined according to the amount of concrete and other aggregate materials, and the losses and disposal during quarrying, processing and transportation.
  - 2) Aggregate processing treatment capacity may be determined according to the monthly average amount of aggregate and other sand stone used during the peak concrete usage period.
- b) The quality of aggregate materials shall comply with the requirements of 6.5.3.3 and 6.5.3.2. The use of alkali-reactive aggregates should be avoided, and if tests with admixtures such as low-alkali cement containing fly ash, shall certify that there is no harmful impact to the concrete, it may be used.
- c) The aggregate borrow area shall be chosen based on the principles of high quality, economy, and local sourcing. If there is insufficient qualified natural aggregate near the main works, the possibility and rationality of quarrying and processing artificial aggregate nearby shall be considered; ballast materials that meet qualification requirements should be utilized; borrow areas should not use, or should use less cultivated land.
- d) The principles for choosing an aggregate processing plant site are as follows:
  - 1) It should be set up near the borrow area; when there is a high usage of aggregates, close transportation distance, and the site conditions allow it, it may also be set up near the concrete plant.
  - 2) A coarse crushing workshop for artificial sandstone aggregate processing should be set up as near the concrete system as possible.
  - 3) Foundations for major equipment shall be stable and possess sufficient load bearing capacity.

- 4) The necessary protection distance from residential areas shall be maintained to reduce the influence of noise and dust.
- e) The volume of the aggregate material product borrow area may be set at 50% to 80% of the monthly average value during peak periods and during flooding and freezing periods when mining ends, an extra margin of 20% of usage during the mining period shall be allowed for. In addition, the volume shall comply with the natural dehydration requirements for the aggregate. If the total volume of the borrow area is large, more rough materials or semi-finished product should be stockpiled, and the stockpile height may be quite large.
- f) Stockpiling and transportation of the aggregate product shall meet the following requirements:
  - 1) The stockpiling yard shall have excellent waste disposal and drainage systems.
  - 2) Partition walls shall be set up to avoid mixing of various aggregates and the wall height may be determined according to the angle of kinetic friction (34° to 37°) of the aggregate, and then adding 0.5 m.
  - 3) The number of trans-shipment times shall be minimised as much as possible. If aggregate of a particle size larger than 40 mm falls through a drop of more than 3 m in disposal, then slow-fall type of equipment should be set up.

7.3.4 Concrete preparation systems shall meet the following requirements:

- a) Calculation of concrete production capacity per hour:
  - 1) Concrete production capacity per hour is calculated according to the Formula (15):

$$P = \frac{q}{nm}k \quad \dots\dots\dots ( 15 )$$

where

*P* is the concrete production capacity per hour, in m<sup>3</sup>/hr;

*q* is the concrete casting intensity in the peak month, in m<sup>3</sup>/month;

*m* is the daily work hours, h, which may be set at 20;

*n* is the monthly work days, d, which may be set at 25;

*k* is the non-uniformity coefficient, which is the ratio of actual maximum hourly casting intensity in the peak month at the average hourly intensity for the total month, which

may be set at 1.5.

- 2) If the surface of the cast bin is quite large, the hourly concrete production capacity shall ensure initial setting does not occur. If the concrete is cast by the smooth spreading method, the Formula (16) shall be employed for calculation:

$$P \geq (1.1 \sim 1.2) \frac{\sum (F \cdot \delta)_{\max}}{t_1 - t_2} \dots\dots\dots ( 16 )$$

where

$\sum (F \cdot \delta)_{\max}$  is the maximum simultaneous grouting volume of all grouting layers;

$F$  is the grouting area;

$\delta$  is the grouting layer thickness;

$t_1$  is the allowable interval time between grouting concrete;

$t_2$  is the transportation time required for the concrete to go from the machinery discharge point to the farthest point of the grouting bin surface.

- b) For hourly production capacity greater than 50 m<sup>3</sup>, an automatic mixing plant should be employed; and for that less than 50 m<sup>3</sup>, a simple mixing station should be employed.

- c) The layout of the concrete system shall keep to the following principles:

- 1) The mixing plant (station) shall be set up as close to the grouting site as possible and shall meet the requirements of blasting at a safe distance.
- 2) The topography shall be properly utilized so as to reduce the quantity of work and the mixing station shall be set up on a stable and strong foundation.
- 3) Overall consideration shall be given to construction requirements for the initial and later periods. Relocation midway shall be avoided as far as possible and disturbance to permanent structures shall be avoided.

- d) The concrete system should have a centralised layout as far as possible; a dispersed layout may be considered under the following conditions:

- 1) Hydraulic structures are scattered over a wide area or the elevation differences are great, with over-intensive grouting. If the layout is centralised, the transportation distance for the concrete is too far and supply is difficult.

- 2) Concrete transportation routes for both sides cannot be connected.
  - 3) Aggregate borrow areas are dispersed, so that transport of the aggregate is inconvenient or uneconomical for a centralised layout.
- e) Total reserves of the aggregate product borrow areas for the concrete system should not exceed the average consumption of concrete grouting for 3 days to 5 days during a peak monthly period, and if this is too difficult, it may be reduced to 1 d of consumption. Cement reserves on the construction site shall be 4 days to 7 days times the average daily consumption of concrete grouting in a peak month for land transportation, and 5 days to 15 days for water transportation. If the interim bins are far from the construction site, this may be increased by 2 days to 3 days.
- f) Supply of cement by a fixed manufacturer shall be planned for and the types should be 1 to 2. Conditions shall be created as far as possible to utilize bulk cement.

**7.3.5 Concrete transportation shall meet the following requirements:**

- a) Concrete transportation shall comply with the requirements of 6.5.3.9.
- b) The concrete transportation mode should be determined according to the factors of work quantity, distribution and distance of feed site, and the size and condition of the grouting site.
- c) The placement method for concrete transportation should be chosen according to the actual conditions at the parts to be grouted:
  - 1) Vehicular trestles or conveyer belts should be employed for foundations and lower dam monoliths where the grouting area is not extensive and the structure is simple.
  - 2) Vehicular chutes or slipping tubes should be employed for dam monoliths that are adjacent to both sides and where the topography is relatively well-utilized.
  - 3) Simple cable swinging concrete tanks should be prioritized for sluices and dams in river channels and arch dams in narrow topography.
  - 4) Crane swinging concrete tanks should be employed for gravity dams and capacious sluices and dams in a river channel.
  - 5) When conditions permit, the method of pumping concrete into the storehouse shall be used for tunnel concrete lining, bored piles and other non-mass concrete.

**7.3.6 Concrete temperature controlling measures shall meet the following requirements:**

- a) In hot seasons, not only 6.5.3.14, but also the requirements in this section shall be complied with. In the cold season, the requirements of 6.5.3.13 shall be complied with.
- b) In order to avoid cracking, comprehensive measures shall be employed regarding structure design, temperature control, rough materials selection, and construction plan and construction quality. Strict temperature control during construction shall be regarded as the major measure to avoid concrete cracking. Both grouting the temperature and maximum temperature rise of the concrete shall meet design requirements, or otherwise the concrete should not be grouted.
- c) The construction technology for concrete shall be modified to improve concrete quality. The concrete shall meet the requirements for strength guarantee, avoid overly high strength and meet the requirements for the construction quality homogeneity indices. The homogeneity index is expressed as  $S_{f_{cu}}$ , the value of the standard deviation of the site specimen's compressive strength of 28-day. The value should be less than 0.18 and the calculation method is listed in Appendix J. When the mix proportion of the concrete is selected, bleeding problems shall be properly solved and bleeding on bin surfaces shall be strictly controlled during construction. During construction crack treatment, all emulsion skin, oil stains, poorly combined aggregates and weak layers caused by bleeding on the bin surfaces shall be cleared away.
- d) Segmentation, jointing and block-formation of concrete placement shall meet the design requirements and those of 7.3.2.
- e) The horizontal casting method for concrete grouting should be employed. If the bench method is employed, obvious benches and gentle slopes (should not be greater than 1 : 2) shall be maintained and attention shall be paid to vibration at the connecting surfaces of the benches.
- f) If cooling pipes are employed for initial cooling, buried pipes shall convey water after being covered by one concrete layer. The water conveying duration is determined by calculation and should be 10 days to 15 days. The temperature difference between concrete and water should not exceed 25 °C. For water pipes with a diameter of 25 mm, flow velocity should be 0.6 m/s. Flow direction shall be changed once a day to ensure uniform cooling of the dam body. During initial cooling, the temperature shall not be reduced by more than 1 °C a day, and in 10 days to 15 days continuous water conveyance, the range of cooling should be 6 °C to 8 °C.
- g) If conditions permit, new techniques for making concrete mixed with magnesia or employing cement with low heat and minimal expansion should be used in order to avoid concrete cracking.

### 7.3.7 Joint grouting of concrete dams shall meet the following requirements:

- a) Joint grouting of concrete dams should be carried out after the internal temperature of the dam body reaches a steady temperature, often in late winter and early spring when the concrete tem-

perature is the lowest.

- b) Before water impoundment, the contact grouting and relevant checks and acceptance work for each grouting area below the lowest reservoir water level in the initial impoundment period shall be completed. After impoundment, the joint grouting of each grouting area shall be carried out when the reservoir water level is lower than the grouting bottom elevation.
- c) Technical requirements of contact grouting of concrete dams shall be enforced according to the design requirements.

**7.3.8** Foundation treatment of concrete dams shall meet the design requirements and those of 6.1.3 and 6.3. A template type concrete dam may be chosen according to the requirements of 6.5.1.

**7.3.9** Concrete sluices and dams may be constructed referring to the requirements for sluice construction.

**7.3.10** A quality management and assurance system shall be established. Relevant technicians, and necessary checking and testing equipment shall be allocated, and the necessary technical management and quality control system shall be established according to the project's scale and the quality control and management requirements. Construction quality control shall meet the following requirements:

- a) Every major key link of raw material, mix proportion and construction of concrete and concrete quality after hardening shall be controlled and inspected.
- b) Quality sampling inspection of raw materials shall meet the requirements of 6.5.3.12. No kind of raw material for concrete shall be utilized until it passes inspection.
- c) The concrete mix proportion shall be determined by tests and shall satisfy the technical index and construction requirements. It may not be employed until it has been examined and approved.
- d) Measuring instruments for the concrete mixing station shall be periodically tested and adjusted, and be sampled and inspected at any time, if necessary. Before weighing of each shift, zero checking shall be carried out on weighing equipment.
- e) Allowable metric deviation of concrete ingredients shall meet the requirements of 6.5.3.8.
- f) The concrete mixture shall be mixed homogeneously.
- g) The concrete collapsed slump shall be inspected 1 to 2 times every 4 hrs. The allowable deviation shall meet the requirements specified in Table 42.



Table 42 Allowable deviation of collapsed slump

Collapsed slump (mm)	Allowable deviation (mm)
$\leq 40$	$\pm 10$
40~100	$\pm 20$
$> 100$	$\pm 30$

- h) Inspection of preparatory work before concrete grouting.
- 1) Foundation surfaces or concrete construction joint surfaces shall be treated according to the requirements. Quality of forms, reinforcement bars and embedded parts shall be inspected, and concrete grouting may not be carried out until the certificate of bin opening has been obtained.
  - 2) If hydro-mechanical structures and electromechanical items are installed and instruments are buried, then before issuing the certificate of bin opening, acceptance shall be carried out according to the relevant standards or documents.
- i) During concrete grouting, specially-assigned persons shall carry out inspection of the bins and record in detail the construction process, problems and solutions.
- j) After stripping the concrete form, the appearance quality shall be inspected. Quality problems or accidents of concrete cracking, honeycomb, surface void, platform stagger and form distortion shall be inspected and treated in good time. If concrete strength or internal quality is suspect, then non-destructive testing methods such as recovery and ultrasonic recovery combined method or drilling for core, and water-pressure tests may be employed for inspection.
- k) For in-situ concrete quality inspection, priority is given to compressive strength. Concrete specimens are mainly randomly sampled at machine discharge points, and three concrete specimens from each group shall be sampled and made of concrete from the same storage hopper or transportation cargo body. The specimen sampling quantity at the grouting site should be 10% of the sampling quantity at machine discharge.
- l) Specimens sampling quantity of concrete of the same strength grade shall meet the following requirements:
- 1) Compressive strength: for large-sized concrete, one group is moulded per 500 m<sup>3</sup> for age of 28-day, and per 1 000 m<sup>3</sup> for design age; for concrete which is not large-sized, one group is moulded per 100 m<sup>3</sup> for age of 28-day, and per 200 m<sup>3</sup> for design age.
  - 2) Tensile strength: one group is moulded per 2 000 m<sup>3</sup> for age of 28-day, and per 3 000 m<sup>3</sup> for

design age.

- 3) Frost resistance, anti-permeability or other main special requirements: proper sampling and inspection shall be carried out during construction and the quantity shall be 1 to 2 groups, according to the main construction part during each season.
- m) Inspection and evaluation of concrete strength shall be implemented according to 6.5.3.12.
- n) For built concrete structures, drilling for core and water-pressure tests shall be properly carried out. For large-sized concrete, drilling for core and water-pressure testing may be carried out by drilling holes at 2 m to 10 m depth per 10 000 m<sup>3</sup> and the evaluation standards for the actual drilling site, inspection items, water-pressure testing sites and absorption rate shall be determined according to the actual status of the engineering construction. For reinforced concrete structures, non-destructive testing shall be the major method for concrete inspection, and if necessary, the hole-drilling method may be employed.

7.3.11 The construction of an RCC dam shall meet the following requirements:

- a) Preparation before paving
- 1) The capacity, working conditions and construction measures regarding equipment for sand and stone material production and storage system, raw material supply, concrete preparation, transportation, paving, rolling and testing shall be checked in combination with the site rolling test, and the construction can be started after meeting the requirements in the relevant technical documents.
  - 2) Technical training shall be carried out for construction workers.
  - 3) Each position shall have the construction organization design for the storehouse surface.
  - 4) Before the foundation block is paved, mortar shall be laid on the bedrock surface and then the cushion concrete or abnormal concrete shall be poured, or the small aggregate concrete or mortar concrete can be directly paved on the bedrock surface. In addition to special requirements, its thickness shall be easy to roll after levelling.
  - 5) Preparations for the formwork, water stopper, steel bars, embedded parts, holes, entrances and exits for the storehouse shall meet the requirements of rapid and continuous paving construction, and special design is required when necessary.
- b) Mixing
- 1) Forced mixing equipment shall be preferred in mixing RCC, and other types of mixing equipment, such as self-falling type mixing equipment, can also be used.

- 2) The weighing system for mixing equipment shall be sensitive, accurate and reliable, and shall be checked regularly to ensure that the weighing accuracy requirements are met in the concrete production process.
- 3) The mixing time, feeding sequence and mixing quantity of RCC shall be determined by the onsite uniformity testing of concrete mixing.
- 4) The mixing equipment shall be equipped with a rapid measuring device for moisture content of fine aggregate and it shall have the function of automatic adjustment of mixing water volume.
- 5) The free fall between the outlet from the discharge hopper and the conveying tool shall be no greater than 1.5 m.
- 6) The batching accuracy and mixing quality of mortar and slurry are the same as that of concrete. The mortar shall be mechanically mixed. A centralized mortar station shall be set up for large-scale projects and equipped with devices to maintain the uniform properties of the mortar.

c) Transportation

- 1) A dump truck, conveyorbelt, negative pressure chute (pipe) and special vertical chute shall be used to transport RCC. Transport equipment shall be thoroughly checked and cleaned before use. If necessary, a cable winch, portal crane, tower crane and other machinery can also be used.
- 2) When using a dump truck to transport concrete, the road must be smooth; the tires of the dump truck shall be cleaned before entering the storehouse and prevent soil and water from entering the storehouse; the vehicles running on the storehouse surface shall avoid sudden braking, sharp turning and other operations that may damage the quality of the concrete surface.
- 3) When using a belt conveyor to transport concrete, measures shall be taken to reduce aggregate separation and mortar loss rate, and sunshade and rainproof facilities shall be provided.
- 4) When using a negative pressure chute (pipe) to transport concrete, the vertical downward elbow shall be set at the outlet from the negative pressure chute (pipe); the partial damage to the negative pressure chute (pipe) cover shall be repaired in good time, and the cover shall be replaced in good time when the damage reaches a certain extent. The slope of the negative pressure chute (pipe) and anti-separation measures shall be determined by field testing.
- 5) Special vertical chute shall have anti-separation function, and if necessary, the control de-

vice to prevent blockage shall be set up.

- 6) When transporting or unloading, the free fall of concrete from the outlet of all kinds of transport equipment shall not be greater than 1.5 m, and a special vertical chute or transfer hopper shall be added when exceeding 1.5 m; when the continuous transport equipment is combined with batch transport equipment, the storage hopper with sufficient volume shall be installed at the transfer place; when using a transfer hopper, measures shall be taken to solve the arch of concrete; the continuous closed transport line from the mixing equipment to the storehouse surface shall be provided with an outlet for waste material and cleaning waste water.
- 7) Measures shall be taken to prevent mortar sedimentation and bleeding, and to ensure that the mortar delivered to the site is even. Mortar can be transported by concrete conveyor or special mortar conveyor.

d) Unloading and levelling

- 1) RCC shall be continuously or intermittently paved with thin layers on a large storehouse surface, and the paving method shall be pouring without longitudinal joint. The inclined-layer placing method and the step method can also be used. The paving area shall be adapted to the paving strength and the allowable interval time between layers of RCC.
- 2) When paving with the method of inclined-layer placing, it is advisable to pave from the downstream to the upstream, so that the layer inclines upstream. The gradient should be no steeper than 1 : 10. The thin layer and sharp angles shall be avoided at the foot of the slope. The secondary pollutants shall strictly be removed before laying mortar on the construction joint surface, and the RCC shall be covered immediately after laying mortar.
- 3) RCC paving shall be paved in a fixed direction and strip by strip. In the range of 3 m to 5 m of the upstream face of dam, the levelling direction shall be parallel to the axis direction of the dam.
- 4) When dump trucks are used to unload materials directly into the storehouse, the height of the stack shall be controlled. Separated aggregates appearing beside the unloading stack shall be evenly distributed into the concrete during the levelling process.
- 5) Unqualified concrete mixtures shall be strictly prohibited from entering the storehouse; those already in the storehouse shall be treated.
- 6) When the compaction thickness is about 300 mm, it can be paved at one time; in order to improve the separation condition or when the compaction thickness is great, it can be paved two to three times.

7) The concrete surface shall be flat and the rolling thickness shall be even after levelling.

e) Rolling

- 1) The selection of a vibration rolling machine shall consider the rolling efficiency, exciting force, drum size, vibration frequency, amplitude, travel speed, maintenance requirements and operational reliability.
- 2) The surrounding parts of the building shall be compacted by vibration roller of the same type, which is directly close to the formwork. For the parts that cannot be close, a small vibration roller can be used. The allowable compaction thickness and rolling times shall be determined by testing.
- 3) The travel speed of the vibration roller shall be controlled within the range of 1.0 km/hr to 1.5 km/hr.
- 4) The rolling thickness and rolling times shall be determined by testing and considered with the comprehensive production capacity of paving, and different rolling thicknesses can be selected according to different conditions such as climate and paving method. The rolling thickness shall be no less than 3 times the maximum aggregate size of the concrete.
- 5) The rolling direction shall be perpendicular to the water flow direction in the range of 3 m to 5 m of the upstream face of dam. The overlapping method shall be adopted in rolling operation. The overlapping width between rolling strips is 100 mm to 200 mm, and the overlapping width of the end shall be about 1 000 mm.
- 6) After the completion of each rolling strip operation, the compacted density of the concrete shall be measured according to the grid layout over time. When the density is lower than the prescribed index, the test shall be immediately repeated and the reasons shall be ascertained, and the treatment measures shall be implemented. If the compacted density satisfies the requirement, the parts where spring soil phenomenon occurs after rolling may not be treated.
- 7) Like the level or cold joint of horizontal construction joints, once the specified rolling times and compacted density are reached, it is advisable to carry out non-vibration rolling for 1 or 2 times.
- 8) When travelling on the finished concrete level, all the kinds of equipment shall avoid damaging the formed surface. Repair measures shall be taken in good time for damaged parts.
- 9) After the RCC is put into the storehouse, the levelling and rolling shall be completed as soon as possible. The maximum allowable duration from mixing to rolling completion shall be tested or analogized according to the different seasons, weather conditions and the

changes of RCC, and it shall not exceed 2 hrs. The edge of the strip in the rolling layer, the edge of the slope of the inclined-layer placing method and the step edge of the step method shall reserve the width of 200 mm to 300 mm and the next strip shall be rolled at the same time when rolling. The time needed to finish the rolling of these parts shall be controlled within the permitted time for direct paving.

f) Joint-forming

- 1) The transverse joint can be formed by the cutting machine, setting the induction hole or the partition. The position of the joint surface, the structural form of the joint and the filling material in the joint shall meet the design requirements.
- 2) When using the cutting machine, it shall adopt the “first cutting, then rolling” or “first rolling, then cutting” manner according to the specific conditions of the project.
- 3) Set the induction hole, which shall be completed within the inter-layer interval. After the hole is formed, the hole shall be filled with dry sand in good time.
- 4) When the partition is set, the distance between the joints of the partitions shall not exceed 100 mm, and the height of the partitions shall be 30 mm to 50 mm lower than the compacted thickness.
- 5) The transverse joints with repeated grouting requirements shall be designed and installed to meet the design requirements.

g) Surface treatment of the layer and joint

- 1) RCC shall be continuously raised and paved and the interval between layers shall be controlled within the allowable time for direct paving. If the layer exceeds the time allowed for direct paving, the mixtures of the cushion layer shall first be laid on the layer, and then a layer of RCC shall be laid on the layer. The layer that exceeds the allowable time for cushion paving is the cold joint.
- 2) The allowable time for direct paving and cushion paving shall be determined by tests, according to the requirements of the engineering structure on the anti-shear capacity and combination quality of the layer, and comprehensively considering the characteristics of the mixtures, season, weather, construction method, different areas upstream and downstream and other factors.
- 3) Construction joints and cold joints must be treated by joint surface treatment, which can be used to remove the floating slurry and loose aggregate on the surface of the concrete by brushing and flushing. Layer treatment is completed and cleaned. After the surface treatment is completed and cleaned and it passes the acceptance inspection, the mixtures

of cushion are paved first, and then the concrete layer is immediately paved before the construction is continued.

- 4) The flushing and brushing time can be determined by field testing according to the construction season, concrete strength, equipment performance and other factors. Don't flush too early.
- 5) Cushion mixtures can be used with mortar, slurry or small aggregate concrete suitable for RCC. The water-binder ratio of the mortar shall be the same as that of RCC, and the strength grade of mortar and small aggregate concrete shall be increased by one grade. Cushion mixtures shall be paved strip by strip like RCC. Among them, the paving thickness of the mortar is 10 mm to 15 mm, and the RCC shall be paved over it immediately, and it shall be rolled before the initial setting of the mortar.
- 6) When the construction is interrupted due to a change to the construction plan, rainfall or other reasons, the paved concrete shall be rolled in good time. The concrete surface of the stopping paving site shall be rolled into a slope surface of not more than 1 : 4, and the part of the slope foot with a thickness less than 150 mm shall be removed. When the construction conditions are again met, construction can be continued after taking corresponding measures to treat the surface of the layer and joint depending on the interruption time.

#### 7.4 Intakes, open channels and forebays

##### 7.4.1 Intake construction shall meet the following requirements:

- a) Intake excavation and grouting shall meet the requirements of 6.1, 6.5 and 6.7.
- b) For a low level intake at the head of a hydraulic tunnel that withdraws water from the reservoir, the relationship between flood control, high slope excavation and concrete grouting shall be properly treated, according to the characteristics of topography, geology, and structure.
- c) Flood control for low level intakes shall meet the following requirements:
  - 1) Underwater concrete shall be completed in one dry season before the flood season.
  - 2) Gates shall have operational capacity during flood periods.
  - 3) The construction cofferdam shall be demolished before the flood season.
- d) For high slope excavation of low level intakes, refer to 6.1.3. Excavation and strengthening shall be carried out according to engineering characteristics, and protection measures shall be employed to ensure stability and safety.

- e) Concrete grouting of low level intakes should take full advantage of topographical conditions, and simple chutes may be prioritized to transport concrete from the top to the bottom; hoisting with tower-type, crawler-type, or other transportation tools, may also be employed depending on the upper precast elements.
- f) For concrete grouting of intake sluices on soft foundation, grouting on a deeper base should be completed before that on a shallower base, and grouting of heavy and large structures should be completed before that of light and thin structures.

**7.4.2 Excavating open channels shall meet the following requirements:**

- a) Conditions of topography, geology and construction shall be considered, and excavation should be carried out part by part and segment by segment. The excavation process shall be correctly chosen.
- b) Earthwork channel excavation shall prevent slope failure. Slag shall not be stacked on the slope top; Drainage shall be unblocked on the slope top to prevent water from flowing into the slope and side structures from being destroyed; a rapid construction method shall be employed to achieve simultaneous excavation and lining.
- c) For common earthwork channels, full-face excavation in one step should be employed. For mechanized excavation of large channels, intermediate grooves should be excavated first, then the left and right slopes, and then manual excavation to reach the bottom and cut the slopes for final channel formation.
- d) For excavation of channels on soft foundations, i.e. quicksand or mucky strata with low bearing capacity, drainage shall be enhanced to keep the ground water level 0.5 m to 1.0 m below the excavation surface. Mechanized construction should employ the method of padding plates or uses tone ballast to convert to foundation. With large machinery on the foundation, backward excavation in reverse method should be employed. Excavation and cutting of a slope should be carried out simultaneously and completed in one step.
- e) Stonework channels shall be excavated by complying with the principles of slope pre-split, excavation from top to bottom and setting berms every time a certain height is reached. Horizontal layering and loose blasting should be employed at mid-channel. Horizontal layer thickness shall be determined by the factor of ensuring the efficiency of excavating and loading machinery. During excavation between the mid-channel and the channel bottom, a thickness of 200 mm to 300 mm shall be reserved for manual excavation to reach the bottom to prevent over-excavation. For channels close to mountains, the slopes above the channel platform shall be excavated first and slope treatment shall be done properly to ensure slope stability.

**7.4.3 Filling of open channels shall meet the following requirements:**



- a) Completely-filled channels. After clearing, the channel may be backfilled by the full face method to the proper elevation above the channel bottom, and the slag at mid-channel does not have to be vibrated and compacted. Then the intermediate groove may be excavated and slag may be disposed of on the left and right dikes and rolled and compacted layer by layer. Finally, cutting of the inside and outside slopes may be carried out in the forward direction. The entire face should be backfilled to a height so as to ensure that slag disposal at the mid-channel satisfies the slag usage of the left and right dikes.
- b) Semi-filling and semi-excavating channels. After clearing, the foundation of the filling area shall first be rolled and compacted with smooth rollers. Soil from the excavation area shall be disposed of in the filling area and shall be vibrated and compacted layer by layer.
- c) Filling shall meet the requirements of 6.1.4.

#### 7.4.4 Anti-seepage engineering of channels shall meet the following requirements:

- a) Anti-seepage materials for channels mainly include soil, cement, masonry, concrete, geomembranes, asphaltic concrete. The technical requirements for each material are listed in relevant regulations.
- b) The deviation in elevation, size and smoothness of the channel foundation trench section shall meet the requirements of Table 43.

**Table 43 Allowable deviation for the channel section**

Item	Allowable deviation (mm)	
	Soil channel	Stone channel
Channel bottom elevation	± (20~30)	± (30~50)
Channel centreline	20~30	30~50
Channel width	+ (30~50)	+ (50~100)
Top elevation of the dike	+ (20~30)	+ (50~100)
Width of upper exit of channel	+ (40~80)	+ (50~100)
Smoothness of channel bottom and inside slope (inspected by 2 m length ruler)	± (20~30)	<30 for convex <100 for concave
<b>NOTE</b> The maximum value is applicable for large and medium-sized channels and the minimum value for small channels.		

- c) Allowable deviation for smoothness and size of the channel anti-seepage engineering is listed in Table 43.

#### 7.4.5 Cement soil anti-seepage shall meet the following requirements:

- a) Soil material shall be air dried and pulverized, and pass through a 5 mm aperture sieve; cement shall employ rain and humidity protection measures.

- b) In-situ paving of cement soil anti-seepage structures shall be carried out according to the following steps:
- 1) Batching shall be carried out according to the design mix proportion, and the allowable deviation in weight shall meet relevant requirements. The time for mixing and paving, or mould packing forming of the cement soil shall be no more than 60 min.
  - 2) Cement soil should be dry-mixed first and then wet-mixed to uniformity.
  - 3) Before paving plastic cement soil, the channel foundation shall be wetted down with purling water and an expansion joint form shall be set up. Channel slopes shall be paved before the channel bottom. Cement soil material shall be uniformly paved, poured and tamped, and patted to compaction. After preliminary floating, a 1 mm to 2 mm thick layer of cement should be spread on the surface, and immediately kneaded, pressed and trowelled. Paving shall be carried out continuously and for the mixing material, paving should be completed within 1.5 hrs after watering.

**Table 44 Allowable deviations of anti-seepage channel section size and structure size**

Item		Allowable deviation value (mm)	
Channel bottom elevation		± (10~30)	± (10~20)
Channel centreline		± (10~30)	± (10~20)
Channel bottom width		+ (20~40)	+ (30~50)
Upper exit width of section		+ (30~50)	+ (40~60)
Smoothness		± (10~20)	± (10~20)
Expansion joint spacing	In-situ grouting	± 20	± 20
	Precast paving	± 50	—
Mitre length of slope of anti-seepage structure		+ (10~20)	+ (10~20)
Longitudinal block-formation length of in-situ construction, and anti-seepage structures of channel slope and bottom		± (5~10)	± (5~10)
Transversal block-formation length of in-situ construction, and anti-seepage structures of channel slope and bottom		+ (30~50)	+ (10~60)
Length difference between two diagonal lines of precast panels		± 7	—
Thickness of anti-seepage structure	In-situ grouting	± 5%	- 5% ~ - 15%
	Masonry anti-seepage and precast paving	± (5% ~ 10%)	—
<b>NOTE</b> The maximum value is applicable for large and medium-sized channels and the minimum value for small channels.			

- 4) For paving dry and harsh cement soil, the form shall be set up first, and then material shall be paved and tamped layer by layer. The paving thickness of each layer should be 100 mm to 150 mm and layer joints shall be scarified and watered.
- 5) For plastic cement soil for the paving protective layer, the protective layer shall be completed before the initial setting of the plastic cement.

**7.4.6** Masonry anti-seepage shall meet the following requirements:

- a) Masonry sequence. For trapezoidal open channels, the channel bottom should be bricked before the channel slopes. When a channel slope is bricked, it shall be started from the slope toe, and masonry shall be carried out from the bottom to the top layer by layer. For U-type and radial open channels, and arched closed conduits, it shall be started from the centre line of the channel bottom, and masonry shall be symmetrically extended to both sides. For rectangular open channels, the flank walls may be started first and masonry shall be extended to the channel bottom. For arched and box-type closed conduits, the flank wall and channel bottom may be started first, and then the top arch or capping plate may be bricked. As the bricking of the channel bottom and slope of various open channels is completed, a sealing capstone shall be bricked in good time.
- b) Stone material location requirements. Large and regular masonry rock blocks shall be bricked at the channel bottom and slope bottom. Masonry stone material and slabstone shall be bricked vertically, i.e., the long edge of the masonry stone material and slabstone shall be parallel to the flow direction and shall be bricked horizontally at the channel bottom. Masonry shall be carried out by staggered joints and the distance between the staggered joints of stone material should be 1/2 of the stone length. The junction of two adjacent rows of masonry pebbles shall be staggered and large pebbles shall be chosen for bricking the channel bottom and slope toe. The larger part of each stone shall be bricked facing down so that the stones shall be wedged in and squeezed in tightly.
- c) Stone material masonry shall meet the requirements of 6.6.

**7.4.7** Concrete anti-seepage shall meet the following requirements:

- a) Construction of the form, reinforcement bar and concrete shall meet the requirements of 6.5 and 6.7.
- b) In-situ concrete. Slide or mobile (reverse turning) forms should be employed and construction shall be carried out by the sequence method block by block. As concrete grouting is completed, float work shall be carried out in good time. For fine and superfine sand concrete, float work shall be carried out twice. After float work, the concrete surface shall be dense, smooth, bright and clean, and no cobbles shall be exposed.

- c) Shotcrete anti-seepage. Strength and thickness of shotcrete shall meet design requirements.
- d) Concrete precast panel anti-seepage shall meet the following requirements:
  - 1) Cracking of the paving seams in masonry with precast concrete panels shall be prevented. For filling channel dikes, masonry should be carried out when the filling body has basically finished settling; the mortar strength of paving seams shall not be less than M10; blocks should not be too large and the length-width ratio should be 1 : 1 to 1 : 1.5.
  - 2) Concrete precast panels shall be bricked by cement or cement mixing mortar and jointed by cement mortar. Masonry shall be smooth and stable, and masonry seam mortar shall be filled in fully, tamped solidly, pressed smoothly, and trowelled.
  - 3) Precast panels shall not be bricked until the foundation trench has been excavated and the foundation stone has been installed. For channels with soil slopes, the space between a precast panel and the soil slope should be solidly filled with hill sand or loam during masonry; for channels with stone slopes, the space between a precast panel and the stone slope should be solidly filled with mortar or concrete during masonry. The top precast panels shall be smoothly filled with mortar and then a sealing capstone shall be installed.

**7.4.8** Membrane material anti-seepage shall be constructed according to the relevant requirements.

**7.4.9** Asphaltic concrete anti-seepage shall meet the following requirements:

- a) Asphaltic mixtures shall be mixed according to the selected mix proportion for asphaltic concrete.
- b) In-situ paving shall meet the following requirements:
  - 1) For anti-seepage structures with levelling cementation layers, the levelling cementation layer may be paved first and then the anti-seepage layer shall be paved.
  - 2) Transportation tools for asphaltic mixtures shall employ heat preservation measures to ensure the in-situ temperature of the asphaltic mixture is not less than the paving temperature.
  - 3) Anti-seepage layers shall be uniformly paved according to the paving thickness determined by in-situ tests. The compaction coefficient should be determined by tests and may be set at 1.2 to 1.5.
  - 4) Asphaltic mixture should be compacted by vibrating rollers. It may be statically compacted once or twice and then vibrationally compacted. For channel slope compaction, vibration shall be carried out when travelling upwards and not vibrating when travelling

downwards. Compaction shall be carried out according to the compacting temperature and durations determined by testing, and compaction shall not fail to be done.

- 5) For places where an anti-seepage layer is connected with structures and where it is difficult to compact with machinery, compaction shall be supplemented by manual work.
  - 6) Asphaltic concrete anti-seepage layers shall be continuously paved to reduce cold joints.
  - 7) If a two layer paving method is employed, joint surfaces shall be dry and clean and a thin layer of warm or attenuated asphalt shall be uniformly brushed on. The brushing quantity shall not exceed  $1 \text{ kg/m}^2$ . The cold joint sites of the upper and lower layers shall be staggered.
  - 8) During construction, proper treatment shall be employed to prevent segregation and over-cooling of the mixture.
- c) Brushing of seal coatings shall meet the following requirements:
- 1) Asphaltic mastic is brushed on a clean and dry anti-seepage layer, and the thickness of the brushing layer shall be uniform. The brushing quantity should be  $2 \text{ kg/m}^2$  to  $3 \text{ kg/m}^2$ . During brushing, the temperature of the asphaltic mastic shall be no less than  $160 \text{ }^\circ\text{C}$ .
  - 2) After brushing, humans, animals and machinery are forbidden to pass.
- d) During construction, fire protection equipment and necessary appliances for labour protection shall be prepared.

**7.4.10** Filling of expansion joints shall meet the following requirements:

- a) Before filling an expansion joint, sundry items and dust in the joint shall be cleaned up and the joint wall shall be kept dry.
- b) Expansion joints should be filled with elastic-plastic sealing materials such as tarplasticdaub, or the bottom part of the joint should be filled with tarplasticdaub and the top part with asphaltic mortar. For expansion joints with special requirements, materials of macromolecular water sealing tubes (belts) should be employed, and macromolecular water sealing tubes supplemented with special rubber should be tamped into joints, and be squeezed in and connected tightly with the joint wall; if the macromolecular water sealing belt is grouted in-situ at the anti-seepage structure, it shall be grouted into the joint wall according to design requirements.
- c) For expansion joint filling, the joint shape shall be regular, and its size shall be qualified, filling shall be tight, and its surface shall be smooth.

7.4.11 Forebay construction shall meet the following requirements:

- a) Excavation and treatment of the forebay shall comply with the design requirements and those of 6.1 and 6.3.
- b) High slope excavation of the forebay shall be carried out according to the requirements of 6.1.3, and protection treatment shall be employed to ensure stability and safety.
- c) For the layout of a forebay on a hill slope, attention shall be paid to preventing hill slope collapse, rock avalanches and storm flood erosion.
- d) Forebay concrete and masonry shall be constructed according to design requirements and the requirements of 6.5 and 6.6.
- e) Civil construction of the forebay shall be coordinated with other relevant specialties such as hydro-mechanical structures.

7.5 Tunnels

7.5.1 General excavation of tunnels shall be done in accordance with the regulations in 6.2.

7.5.2 The lining of concrete in-situ shall be in accordance with the following requirements:

- a) The construction procedure of barrel lining. The operations of tunnel lining and excavation can be carried out in the same sequence or in parallel and overlapping, to be decided according to specific analysis of the factors of tunnel length, section size, surrounding rock characteristic, construction equipment and construction period requirements.
- b) Concrete casting subsection. The subsection of concrete casting shall be decided according to comprehensive analysis of the surrounding rock condition, concrete supply capability, casting speed and form structure, as well as the requirements for hydraulic structures. When there is no design regulation, a length of 8 m to 12 m can be adopted.
- c) Concrete block-formation. The block-formation of tunnel lining sections shall be decided according to conditions such as the surrounding rock condition, tunnel section shape and size, form structure, construction method and organization:
  - 1) Lining at one time for the whole section without block-formation; suitable for tunnels with small and medium-sized sections, with high speed casting and good geological conditions. When the geological conditions are poor, shotcrete-bolt support can be done before the whole section lining (secondary lining).
  - 2) Divided into two parts as invert and side roof arch; pouring the invert before the side and

roof arch is suitable for various kinds of section tunnel with good geological condition; pouring of side and overt before the invert is suitable for various geological conditions and large section tunnels.

- 3) Divided into four parts of overt, side walls and invert; when the geological conditions are poor and digging is required at the same time as arching, pour the overt (with joist) first and then pour the side walls and invert.
- d) Joint treatment of the lining shall meet the following requirements:
- 1) Ring direction joint: for ring direction construction joints of a free-flow tunnel without anti-seepage requirement, it is allowed that the distributed reinforcement does not go through the joint surface and that there is no watertight seal, but surface roughening shall be done to the joint; for ring direction construction joints of a free-flow tunnel with anti-seepage requirement or pressure tunnel, surface roughening treatment for the joint is required and the distributed reinforcement shall go through the joint surface, and have watertight sealing; ring direction expansion joints shall be treated according to design requirements.
  - 2) Longitudinal joint: the invert central angle of the lining block for circular tunnels shall be controlled to within around  $100^\circ$ ; the surface of longitudinal construction joints shall be roughened and longitudinal construction joints shall be set up at places where the tensile stress and shear stress are relatively low while key grooves shall also be set up. If there are anti-seepage requirements, watertight sealing shall be installed; if invert lining is carried out after side and overt lining, the joint surface (surface of the inverse joint) shall be treated appropriately.
- e) Reinforcement construction shall meet the following requirements:
- 1) Reinforcement subsection: The ring direction reinforcement of circular tunnels can be divided into overt, side arch and invert. For large diameter cross sections, further subsections are needed, according to the process, transportation and installation conditions; ring direction reinforcement of the door-type tunnel can be divided into the horizontal reinforcement in the overt, side wall and bottom floor, together with the “L” reinforcement in the side wall. The reinforcement in high side walls can be divided into casting height of each layer; axial reinforcement shall be divided according to the length of the casting section.
  - 2) Reinforcement installation: in-situ installation shall be used for all reinforcement. For overt or the side arch of circle tunnels, the reinforcement should be installed after the formwork is set up.
- f) Construction of formwork shall meet the following requirements:
- 1) Tunnel lining formwork shall be selected according to the lining construction procedure,

construction conditions, design requirements, surrounding rock conditions and section shape and size and the kind of tunnel lining can be ordinary formwork, steel trolley, sliding mode and scraper mode. For long tunnels with good surrounding rock, a full-section steel mould trolley is the best choice.

- 2) When calculating the formwork loading, the weight of the allowable overbreak amount or overfilling concrete for collapsed sections shall be fully considered. When using a concrete pump in arch sealing, the additional pressure of concrete pumping shall be considered when calculating the formwork load.
  - 3) The formwork removal time shall be in accordance with the regulations in 6.5.1.6; besides, factors like the stability level of the tunnel’s surrounding rock, section shape, span and exterior load shall be considered. When there is a calculation test for demonstration, the time of form removal can be advanced as appropriate.
- g) Concrete casting shall meet the following requirements:
- 1) Placement method: pumping shall preferably be selected for the placement of the concrete for side and over; the placement of invert concrete can be done directly by a carrier vehicle or belt conveyor.
  - 2) The casting of pumped concrete shall be in accordance with the regulations in 6.5.3.21.
  - 3) When transporting concrete using a belt conveyor, the maximum dip angle shall not exceed the values listed in Table 45. For concrete mix proportion, the sand ratio shall be appropriately increased, the maximum grain size should not exceed 80 mm, and the cement content can be 50 kg/m<sup>3</sup> to 75 kg/m<sup>3</sup> lower than for pumping. The running speed of the belt conveyor should not be greater than 1 m/s to 1.2 m/s.
  - 4) The following items shall be paid attention to in concrete casting: the casting of side wall arches shall done layer by layer, both sides shall rise symmetrically and uniformly; if casting is interrupted, the construction surface shall be chiselled into a radial joint surface; when the invert is constructed using a drawing die, there shall be measures to prevent floating.

**Table 45** The maximum dip angle of the belt conveyor when transporting concrete

Concrete slump (mm)	Upward transportation	Downward transportation
<50	16°	8°
50~100	14°	6°
100~160	12°	4°

**7.5.3** Masonry rock block (rock material, concrete precast block) lining shall meet the following requirements:



- a) Masonry construction shall be in accordance with the regulations in 6.6. The vertical alternate joint of the upper and lower layers of a side wall shall not be less than 100mm. The overbreak part behind the wall shall be filled up by masonry.
- b) When building the arch ring following the method of “wall before arch”, T-shape stones shall be extended out, or holes allowed for, or pillars shall be set up on both the left and right sides of the top of the side wall, as supports for installing the arch frame. Install and lay symmetrically from both sides of the arch springing and the overbreak part of the arch roof shall be filled up densely.
- c) When building the arch ring following the method of “wall before arch”, reinforced concrete joists shall be grouted at the arch springing as support for the arch ring.

#### 7.5.4 The lining of concrete precast components shall meet the following requirements:

- a) Component block-formation: the lateral or longitudinal width of the component shall be decided based on a comprehensive analysis of the surrounding rock stability, the force condition of the component and the prefabrication, transportation and installation of the precast component, as well as backfilling.
- b) The installation of concrete precast components is carried out using an installation trolley. During transportation, the components are folded and located at the lower part of the trolley and unfolded and installed at the installation location.
- c) The connector of the precast component shall be constructed according to the design stipulation. For rigid connectors, a step-gap shall be allowed for at the connector during construction, reinforcement is extended out, and when the component is in position, centre weld the reinforcement and pour secondary concrete at the connector. Flexible connectors shall be used if small compression distortion or rotational distortion is allowed at the location of the component connector.
- d) Watertight seal construction shall meet design requirements and the regulations in 6.5.3.15 shall be consulted.
- e) The contact surface of the joint shall be roughened, cleaned and filled up with mortar that has the same strength grade as the concrete and pointing on the surface of the circular seam shall be carried out.

#### 7.5.5 Tunnel grouting shall meet the following requirements:

- a) The grouting for the concrete lining section of hydraulic tunnel shall be carried out in the sequence of backfill grouting followed by consolidation grouting. Backfill grouting shall be carried out when lining concrete reaches 70% of design strength. Consolidation grouting should be car-

ried out 7 days after the backfill grouting is finished. When curtain grouting is arranged in a tunnel, the construction shall be carried out in the sequence of backfill grouting, consolidation grouting and curtain grouting.

- b) Grouting for hydraulic tunnel steel lining shall be carried out in the sequence as required by design. The steel lining contact grouting shall be carried out 60 days after lining concrete pouring is finished.
- c) At the end of grouting, grouting holes with grout flowing outwards or upwards shall be stopped grouting for coagulation.
- d) Distortion monitoring devices shall be installed for observation and recording, if necessary.
- e) Backfill grouting shall meet the following requirements:
  - 1) Top arch backfill grouting shall be divided into sections, each section should not be longer than three lining sections, and the end of the section shall be sealed tightly during concrete construction.
  - 2) Grouting holes shall be arranged on the centre line of the tunnel arch and within a range of 90° to 120° of the central angle of top arch. Row spacing of grouting holes can be 3 m to 6 m and each row can have 1 to 3 holes.
  - 3) The direct drilling method should be used for grouting holes in concrete lining, and the drilling in embedded guide pipe shall be adopted for reinforced concrete lining. The borehole diameter should not be less than  $\phi 38$  mm, the borehole depth should be drilled through the cavity or into the surrounding rock for 100 mm, and the thickness of concrete and the size of cavity between the concrete and the surrounding rock shall be measured and recorded.
  - 4) When backfill grouting is applied in areas with surrounding rock collapse, karst cave and over-excavation, grouting pipelines and exhaust pipelines shall be embedded when concrete is placed, and grouting shall be performed through pipelines. The number of buried pipes shall be no less than two and the location is determined on site.
  - 5) Before grouting, joints and defects in lining concrete shall be completely inspected and possible grout leakage areas shall be processed first.
  - 6) For grouting by using the pure pressure grouting method, it should be constructed in two sequences and the hole in the later sequence shall include the top opening.
  - 7) Backfill grouting shall start at the lower end and go towards the higher end. The holes in same sequence in the same section can be grouted after all or part of the holes are drilled. Single hole drilling in sequence and grouting can be carried out.

- 8) When the lower holes are grouted, the higher holes may be used for exhausting air and draining water. When the slurry is discharged from the higher hole (close to or equal to the water cement ratio of the injected slurry), the lower hole can be blocked and the grouting in the higher hole is carried out. In such a sequence, this process will continue till the end.
- 9) The water cement ratio of the slurry can be Grades 1 and 0.5 and the holes in first sequence can be directly grouted with Grade 0.5 slurry. Cement-based mixed slurry or high-fluidity concrete shall be poured into the parts with large voids. When cement mortar is used, the sand content should not exceed 200% of cement weight. Cement clay grouting or other composite grouting should be used for backfill grouting of tunnel culverts in fully-weathered or loose soft rock mass.
- 10) Grouting pressure shall be determined according to the thickness of the concrete lining and reinforcement conditions. In plain concrete lining, grouting pressure of 0.2 MPa to 0.3 MPa can be used, and in reinforced concrete lining, grouting pressure of 0.3 MPa to 0.5 MPa can be used.
- 11) Grouting shall be carried out continuously. Grouting holes with grouting stopped due to accidents shall be cleaned and then grouting shall be resumed until the completion of work.
- 12) Grouting completion conditions: under prescribed pressure, the grouting hole stops suction, and the grouting can be completed after continuous grouting for 10 min.
- 13) Grouting holes shall be tightly sealed using cement mortar after grouting is completed. The hole openings shall be pressed and levelled.
- 14) Backfill grouting quality can be inspected through an inspection hole grouting experiment or core examination. The inspections will be conducted 7 days and 28 days after grouting completion. Inspection holes shall be arranged in the centre line of the top arch and parts with large voids and abnormal grouting conditions. Holes shall penetrate the lining and go 100 mm into the surrounding rocks. For pressure tunnels, one or one pair, of inspection holes should be arranged every 10 m to 15 m and the number of inspection holes for free-flow tunnels can be reduced appropriately.
- 15) The construction quality inspection of backfill grouting shall meet the following quality standards and one or two inspection methods can be selected according to engineering conditions. For parts that do not require cavity filling, the slurry filling thickness shall meet the design requirements.
  - Single hole grouting test. Cement slurry with a water cement ratio of 2 is injected into the inspection hole and the pressure is the same as that for grouting. It is qualified to inject no more than 10 L slurry in the initial 10 min.

- Double-hole connectivity test. Two inspection holes with a distance of 2 m are arranged at the designated position. Cement slurry with a water cement ratio of 2 is injected into one of the holes. The pressure is the same as the grouting pressure. If slurry output from the other hole is less than 1 L/min, the test is passed.
  - Check inspection holes and core sample. Check boreholes and observe cores, if the setting of slurry is densified and meets design requirements, it is regarded as qualified.
- f) Consolidation grouting shall meet the following requirements:
- 1) Grouting can be carried out using the pure pressure grouting method according to the principle of grouting by sequences between rings and densifying inside the ring. Grouting between the rings of surrounding rocks Grades IV and V should be conducted by two or three sequences. The grouting between the rings of surrounding rocks of Grades II and III may be conducted without following sequences.
  - 2) Grouting holes can be drilled by a pneumatic drill or other types of drills. The diameter of drill-hole finished should not be less than  $\phi 38$  mm. The position, direction, and depth of the hole shall meet the design requirements.
  - 3) The fissures for consolidation grouting holes shall be flushed with pressure water before grouting and the flushing time should not be more than 15 min or the flushing should stop when the backwater is clean. The washing pressure can be 80% of grouting pressure and no greater than 1 MPa. Whether to flush or how to flush should be determined via field tests in complex geological conditions or for special requirements.
  - 4) Consolidation grouting should employ the single hole grouting method. In areas with small grouting volumes, grouting holes on the same ring can be grouted together. The number of grouting holes to be simultaneously grouted should be no more than three and the position of the holes should be symmetrical.
  - 5) When the bedrock of consolidation grouting holes is less than 6 m in length, grouting can be conducted for all holes for once. When geological conditions are poor or there are special requirements, grouting can be conducted by segments.
  - 6) Consolidation grouting pressure for the tunnel can be 0.3 MPa to 2.0 MPa; and grouting pressure for the tunnels with high head shall be determined through a grouting test according to engineering requirements and the geological conditions of surrounding rocks.
  - 7) The grouting slurry water cement ratio and slurry conversion & termination conditions shall meet the following requirements:

- The water cement ratio of grouting slurry may employ four grades, including 3, 2, 1, and 0.5. The water cement ratio of the slurry at the beginning of grouting is 3. The slurry conversion principle is as follows: When grouting pressure remains unchanged, the injection rate continues to decrease, or when the injection rate remains unchanged and the pressure continues to rise, the water cement ratio shall not be changed; when injected grouting volume has reached 300 L or more, or when the grouting time has been maintained 30 min, the grouting pressure and the injection rate have not changed or have changed insignificantly, the water cement ratio with denser grade shall be used; when the injection rate is greater than 30 L/min, the ratio can become more concentrated over grades according to the specific circumstances.
  - Termination conditions of grouting in each section shall be determined according to geological conditions and engineering requirements. When the grouting section is under the maximum design pressure and the injection rate is no more than 1 L/min, the grouting can be completed after continuous grouting for 30 minutes.
- 8) After grouting is completed, accumulated water and dirt in the borehole shall be removed, the holes shall be sealed using the “full-hole grouting” or “duct grouting” methods, and the left part of the holes shall be filled with dry hard mortar and levelled.
  - 9) The engineering quality inspection for consolidation grouting of surrounding rocks shall be mainly based on measurement of elastic wave velocity of grouted rock mass and supplemented with the water pressure test for permeability measurement. The acoustic wave method or the seismic wave method should be used for the elastic wave test. The single point method is used for the water pressure test.
  - 10) The elastic wave velocity testing of surrounding rocks shall be conducted 14 days after grouting is completed. The layout of the inspection holes, selection of testing instruments, and quality standards shall be consistent with the design specifications.
  - 11) Inspection with the consolidation grouting pump-in test should be conducted 3 days after grouting is completed. The number of inspection holes should not be less than 5% of the number of all grouting holes. The permeability of testing sections with a qualification rate of greater than 80% is no greater than the design stipulation, and the permeability of other sections is no greater than 150% of the design value. The distribution is not centralized. The single point method is used in the water pressure test.
- g) Steel lining contact grouting shall meet the following requirements:
- 1) The contact area of the steel lining and the position of the grouting hole can be determined through percussion inspection on the site. Grouting should be carried out for void areas larger than 0.5 m<sup>2</sup> and the number of holes arranged in each separated void area shall not be less than two. Both the lowest and highest points shall be arranged with holes.

- 2) Steel lining contact grouting holes can be reserved on the steel plate, screw threads should be provided inside the holes, and fortified steel plates should be welded outside the steel lining of the pre-setting holes. The short grouting pipe and the steel lining can be threaded or welded.
- 3) Connecting holes shall be set on the stiffening ring of the steel lining and the hole diameter should not be less than 16 mm, so as to facilitate the flow of slurry.
- 4) A magnetic drill should be used to drill grouting holes on the steel lining and the hole diameter should not be less than 12 mm. The dimensions of the gap between the steel lining and concrete should be measured for each hole.
- 5) Clean compressed air shall be used to check connection of gaps before grouting, and dirt and water in the gaps shall be blown away. The wind pressure shall be less than the grouting pressure.
- 6) Grouting pressure shall be controlled as that the steel lining distortion would not exceed the design value. The pressure can be determined according to the shape, thickness of steel lining, void area, and void degree, which should not be more than 0.1 MPa. When the depth of the voids is great, the influence of slurry weight shall be considered in the grouting pressure.
- 7) The water cement ratio of grouting slurry can be 0.8 or 0.5 and the water reducer should be added to the slurry.
- 8) Grouting shall start from the lower holes. In the grouting process, knock and vibrate the steel lining. When high holes discharge thick slurry respectively, close their orifice valves by sequence. At the same time, the volume and concentration of slurry discharged from each hole shall be measured and recorded.
- 9) Under design pressure, the grouting hole stops suction, and then the grouting may stop after the grouting continues for 5 min.
- 10) If the one-time grouting fails to meet the design requirements, measures, such as re-grouting, or using fine cement slurry or chemical slurry, can be implemented.
- 11) Grouting holes can be sealed through plug welding or welding after the grouting is completed, and the grinding wheel is used to grind the orifice.
- 12) Contact grouting of steel lining can also be carried out by means of pre-embedded special grouting pipes or grouting boxes without drilling holes and the technical and quality requirements shall be consistent with the design specifications.

- 13) The grouting quality shall be inspected 7 days after grouting is completed by using the percussion method or other methods. The scope and degree of steel plate void shall meet the design requirements.

7.5.6 The operational security of tunnel construction shall meet the following requirements:

- a) The transportation, storage, processing and in-situ charging of the blasting material, as well as the treatment of misfire shall all be carried out according to relevant safety operation specifications. The selected blasting material shall be in accordance with relevant national technical standards, and its performance checked before use. New-type blasting materials can only be used when their performance has proven to be in accordance with regulations and approved by the departments in charge of security and technology.
- b) A high enough ventilation rate and duration shall be ensured after blasting, and entering the blasting surface too early is prohibited. Digging of an un-blasted hole is forbidden and measures shall be taken to prevent stray current and static electricity from causing harm.
- c) After blasting and before entering the tunnel, the stability of the rock and stratum shall be checked. Check the condition of critical rock carefully and deal with it seriously, until the tunnel roof lining is finished.
- d) When going through special strata or finding unusual signs, special technological measures for disaster prevention shall be developed, according to specific construction conditions.

## 7.6 Aqueducts

7.6.1 The construction of aqueduct foundations shall meet the following requirements:

- a) The excavating, backfilling and treatment of the foundation of aqueducts shall meet design requirements and the requirements of 6.1 and 6.3.
- b) The allowable error for masonry or concrete gravity pier foundations shall meet the requirements of Table 36.
- c) The construction of digging piles and bored piles shall meet the requirements of 6.3.

7.6.2 The supporting structures of aqueducts shall meet the following requirements:

- a) Pier supports. Concrete and masonry pier supports shall meet the design requirements and the requirements of 6.5 and 6.6. The allowable error can be referred to in Table 36.
- b) Cast-in-place concrete bents. The order of concrete placement of bents shall be properly arranged. Control the rising speed of concrete to be around 1.0 m/hr. Before the bent concrete

placement, the formwork supports shall be strengthened to maintain the stability of the formwork. During the placement process, the bent shall be observed at all times. If there is any deflection, it shall be adjusted right away.

- c) Prefabrication and hoisting of bents. The hoisting and installation of bents shall meet the requirements of 6.7.
- d) The allowable error of the cast-in-place and prefabricated bent installation shall meet the requirements of 6.5.3.12 and 6.7.3.
- e) The construction of arch structures built by masonry or concrete precast blocks shall meet the requirements of 6.6.12 and other relevant requirements.
- f) Fabricated rib arches. The prefabrication, transporting and hoisting of rib arches shall meet the requirements of 6.5 and 6.7.

**7.6.3** The construction of cast-in-place concrete aqueduct bodies shall meet the following requirements:

- a) The formwork supports for the cast-in-place concrete aqueduct body shall meet the requirements of 6.5.1.
- b) The casting order of the cast-in-place concrete aqueduct body can be from one end to the other end, from both ends to the centre or from the centre to both ends. Aqueducts of small section shall be poured uniformly.
- c) Divide the aqueduct body into several layers by different methods according to different types of aqueduct body. Carefully determine the height of each layer and divide into as few layers as possible. The number of layers should be no greater than four. The height of the first layer shall be greater than the other layers.

**7.6.4** The construction of prefabricated concrete aqueduct bodies shall meet the following requirements:

- a) The selection of the prefabrication site shall consider the landform, roads, transportation distance.
- b) The casting of formwork supports is the same as that of prefabricated concrete aqueduct bodies.
- c) The care and maintenance duration for the concrete aqueduct body should be no less than 28 days.
- d) When hoisting the aqueduct body, the concrete strength shall have reached the design strength.



7.6.5 Since the construction of aqueducts is a kind of high-altitude operation, the hoisting and transporting equipment shall be selected according to the practical situation of each aqueduct. If conditions permit, the cable cranes shall be selected first.

7.6.6 If the two ends of the aqueducts are connected with filling canals, not only shall the filling quality of the joints meet the relevant requirements, but also pre-settlement of the filling shall be carried out. The construction quality of the contact surface of cutoff rings on the ends of aqueducts and the filling soil shall be paid attention to.

7.6.7 The type of the expansion joints' waterstop shall meet design requirements and the requirements of 6.5.3.15.

7.6.8 The technical management of construction and hoisting of aqueducts shall be strengthened to make sure the construction scheme has been approved, the division of labour is clear, the measures and responsibilities are in place and the construction is properly organized through a unified command structure.

## 7.7 Surge shafts

7.7.1 The surge shaft(hereafter referred to as a shaft) construction method shall be determined according to factors such as the surrounding rock stability, excavation section size, upper and lower channel conditions of the shaft, form of the roof structure, the influence on the construction of upper structures after extended excavation of the lower parts, as well as construction equipment. The following contents shall be included:

- a) Flow process suitable for small and medium-sized section shafts with surrounding rock of types I and II or with surrounding rock of type III with shotcrete-anchorage support which can keep the surrounding rock stable, or for large section shafts with good stability.
- b) Segmented flow process suitable for large and medium-sized section shafts with surrounding rock of types III and IV, or shafts with poor local conditions needing timely lining, or large sections shafts with surrounding rock of types II, III and IV.

7.7.2 Shaft excavation shall meet the requirements in 6.2.

7.7.3 Reinforcement of a wellhead in open air shall meet the following requirements:

- a) Wellhead side slopes shall be reinforced according to the requirements for the side slope to keep the surrounding rock stable. The excavation size of the well stage shall be decided according to the construction conditions and the requirements of the upper buildings. A platform of 3 m to 5 m should be allowed for on each side. Drainage channels shall be allowed for at the side slope foot to prevent surface water from draining into the well.

- b) For large section shafts, after excavation to a certain depth from the wellhead top, reinforcement shall be done according to the stability conditions of the surrounding rock, or lining shall be done beforehand according to the requirements for permanent buildings, so as to ensure the stability of the upper surrounding rock while excavating.

**7.7.4** The reinforcement of imbedded wellheads shall meet the following requirements:

- a) When a concrete structure is adopted for the upper part of the shaft, for the convenience of setting up the form and the safety of lower part construction, the concrete construction of the upper part should be carried out before the excavation of the lower part, which is good for the stability of the surrounding rock.
- b) The surrounding rock at the connecting segment between the shaft and the high pressure pipeline inclined shaft usually has weak resistance to any stress, and shall be reinforced before construction of the shaft.

**7.7.5** Temporary supports shall meet the following requirements:

- a) Temporary supports after shaft excavation shall meet the requirements in 6.2.
- b) When the rock of a small section shaft breaks, the method of protecting the shaft wall using in-situ concrete can be adopted.
- c) Sections with surrounding rock of types IV and V shall be reinforced in a timely manner. The method of lining while digging, or digging while lining or pre-grouting to reinforce the rock can be used.
- d) When there is an unfavourable joint composition in the shaft wall, anchorage shall be done in a timely manner.

**7.7.6** Steel bar subsection construction shall meet the following requirements:

- a) For construction using ordinary forms, circumferential steel bars shall be segmented according to the actual size, and vertical bars shall be segmented according to the standing elevation of the form each time.
- b) For construction using sliding mode, the vertical bars (or axial bars) should be no longer than 6 m, and the circumferential bars should not be longer than 7 m.

**7.7.7** Steel bar installation shall meet the following requirements:

- a) For construction using ordinary forms, the vertical steel bars shall be installed in advance of the formwork erection; circumferential steel bars shall be installed after erection.

- b) For construction using sliding mode, shaft body steel bars shall be installed by subsection, and pouring shall be carried out at the same time as installing for circumferential steel bars.

**7.7.8** Concrete lining shall meet the following requirements:

- a) The subsection elevation for shaft concrete lining shall be decided according to the surrounding rock stability condition, lining structure type and pouring method.
  - 1) If the surrounding rock stability is poor, the shafts should be excavated by subsection, and lined by subsection.
  - 2) When the lining structure type is changed, the changing point should be poured by subsection.
  - 3) When ordinary form is used in the pouring of large section shafts, it can be divided into an even number of blocks for pouring, according to form structure, mixing capacity and transportation capacity.
- b) The concrete placement method shall be decided according to the construction condition. When the shaft depth is within 15 m, a descent control tube can be directly used to transport the concrete into position; if the shaft depth is between 15 m to 100 m, the concrete should be transported using a vibrating chute to the pouring platform erected at the bottom, and then put in place by a descent control tube; if the shaft depth is too deep, or the concrete mixing plant is located under the shaft, a cage should be used to transport concrete.
- c) Sliding form should be used for shaft concrete lining. The form can be made into whole or assembled structures according to the shaft diameter and section shape, and be fixed together using loops. Form height depends on the concrete setting time and form climbing rate, and the climbing rate should generally be 1.0 m/day to 1.4 m/day. The form shall be cone-shaped with the bottom slightly smaller than the top, the taper is usually 1% and the strength of the demoulding concrete for the sliding form should be 0.1 MPa to 0.3 MPa.
- d) The circumferential and longitudinal construction joints of concrete lining shall not only be given roughening treatment according to the requirements for common construction joints, but key ways shall also be made; if there are waterproofing requirements, a water-stop shall be set up.

**7.7.9** Construction safety operation shall meet the following requirements:

- a) When the pilot shaft and shaft body or wellhead are operated together, reliable sealing measures shall be used.
- b) A shaft depth indicator shall be set up when a lifting device is adopted in a shaft to prevent overwinding and overspeed, and there shall be protection devices for overcurrent and voltage

loss, as well as a braking system. There shall be reliable communication and signal connections and the signals shall include sound and light.

- c) A foot ladder with a guardrail shall be installed in the shafts and a resting platform shall be made every 8 m.

## 7.8 Civil construction of penstocks

7.8.1 Underground buried penstock excavation shall meet the requirements in 6.2.

7.8.2 The concrete construction of underground buried penstock without steel board lining shall meet the following requirements:

- a) Inclined shaft concrete lining should be poured using sliding form. Steel form shall be made into a conical shape, with the front end big and the tail end smaller, and the taper from 3‰ to 8‰. The panel shall be flat and the allowable deviation of the convex-concave is 2 mm to 3 mm. Sliding form lining is divided into covering lining and contra-aperture lining and priority should be given to the use of covering lining.
- b) Concrete performance shall have an initial setting time of no less than 1.5 hrs, final setting time longer than 4 hrs and slump of 40 mm to 60 mm.
- c) If the inclined shaft slope is between 30° to 45°, use a chute for concrete pouring and the chute shall be capped; set up a metal baffle every 5 m to 8 m and a baffle shall also be set up at the end of the chute to prevent the concrete from separating. When the length of the inclined shaft is large, trolleys or skips shall be used to transport concrete to the top of the pouring storehouse, and then use the chutes for transportation into the storehouse.
- d) When using a sliding form for concrete pouring, attention shall be paid to the following items:
  - 1) The overt should be poured first; left and right sides shall be symmetrically poured.
  - 2) The sliding time interval for sliding form shall be decided through tests, and shall usually be kept around 0.5 hr, with a maximum of no more than 1 hr. The pull stroke of the form each time should be 50 mm to 100 mm and daily footage should be 2 m.
  - 3) The form position shall be adjusted at any time, but each time it should not be more than 100 mm (radial).
  - 4) The form surface shall be kept smooth, to avoid scraping off any concrete during movement.

**7.8.3** The conditions of and procedures for an underground embedded penstock shall meet the following requirements:

- a) Before installing a penstock, the following conditions shall be met:
  - 1) After excavation of the rock in the cave, a clearance of 400 mm shall be left at the top and side of the horizontal pipe and a clearance of 500 mm should be left at the bottom. A clearance of 400 mm shall be left around the inclined shaft; the clearance shall be appropriately increased for those with a small diameter.
  - 2) The concrete buttress or wall supporting the penstock shall have a strength above 70%.
  - 3) The diameter of the anchor bar embedded around the penstock shall be no less than 20 mm, and the mortar in the embedding hole shall have a strength above 70%.
  - 4) Observation control points shall be securely set up with obvious markings. The number and position of control points shall meet the installation requirements.
  - 5) Build staging, set up safety protection devices and establish clear contact signals. When the inclined shaft is long, effective ventilation and smoke exhaust shall be installed.
- b) Installation procedure and principles
  - 1) Penstock installation procedures shall be decided considering factors including penstock entry, concrete feeding direction, the number of working surfaces, construction period and geological conditions.
  - 2) When hoisting and transporting conditions permit, large section installation should be favoured. Penstock installation and concrete pouring should be carried out alternately by section, and the length of each section shall be based on the precondition of ensuring concrete pouring quality. The concrete housing should be done by pumping.
  - 3) Measures shall be taken to prevent floating and distortion of steel pipe during installation.

**7.8.4** Exposed penstock construction shall meet the following requirements:

- a) The excavation of the penstock line shall meet the requirements in 6.1.3, pre-splitting blasting shall be adopted around the pipe seat, collapsed rock shall be cleared and good drainage and side slope treatment measures implemented.
- b) The construction of anchorage blocks and buttresses shall meet design requirements and also meet the requirements in 6.5 and 6.6, and 6.1.3.

- c) The procedure and requirements for penstock installation shall meet the following requirements:
- 1) During the production and installation of penstock, distortion or damage shall be avoided.
  - 2) Select the correct installation procedure, i.e. install and fix the elbows, then, according to the position of the expansion joints, install from bottom to top (when the expansion joint is very near to the downstream side of the anchorage block), or in upstream and downstream directions (when the expansion joint is between two anchorage blocks),.
  - 3) Penstock temperature shall be measured in a timely manner during installation and based on this, correctly determine the surplus length of the expansion joint.
  - 4) Longitudinal joints of adjacent pipe sections shall not be arranged to be on the same straight line.
  - 5) Cableway hoisting or flat penstock rail wagons can be used to transport penstock, according to the construction conditions.
  - 6) The bottom of the penstock shall be at least 600 mm higher than ground level.
  - 7) The measurements during construction should be carried out at fixed times or when the sunshine is not strong.
  - 8) Other requirements shall meet the requirements in 8.4.

**7.8.5** The construction of reinforced concrete penstocks shall meet the following requirements:

- a) The construction of the pipe bed and pipe socket shall meet the following requirements:
- 1) The penstock bed excavation shall follow the requirements in 6.1.
  - 2) The soil foundation penstock bed shall be densely compacted. Rigid penstock bed cushions shall be laid on a good rock base. Concrete or masonry rock block construction shall follow the requirements in 6.5 and 6.6. The quality of the soil filled in on the top of embedded penstocks shall meet design requirements.
  - 3) Asphalt painted on or asphalt felt laid between penstock lines and supports shall meet the design requirements.
- b) The construction of anchorage blocks shall meet the requirements in 7.8.4.
- c) The interval distance between expansion joints of cast-in-place reinforced concrete should be 15 m to 20 m for soil foundations, and 10 m to 15 m for a rock base. There are two types of

pipeline joints, opening style and telescopic style, and selection priority shall be given to the latter. The width of the expansion joint should be 15 mm to 20 mm. The quality of pipeline joints and expansion joints shall meet design requirements and the requirements in 6.5, and ensure hermetic sealing.

- d) The precast reinforced concrete pipe section length is determined according to specific conditions of production, transportation and installation, and generally should not be longer than 5 m. Socket type pipes shall be selected in priority as the pipe section form. During pipe section hoisting, the concrete strength shall meet the design requirements. When there are no design requirements, it shall not be less than 70% of design strength. The position, form and sealing material for the subsidence seam and expansion joints, and the sealing material for pipe section joints shall all meet the design requirements. The sealing material shall be firmly bonded, and strictly plugged, without leakage phenomenon. The allowable deviation for precast pipe section installation shall meet the requirements in Table 46.

**Table 46 Allowable deviation of precast pipe section installation** Unit: mm

No.	Item	Allowable deviation
1	Pipe section installation axis displacement	$\pm 5$
2	Surface elevation difference between adjacent two pipes	3
3	Width of subsidence seam and expansion joint	$\pm 5$
4	Difference between gap value for the same connecting joint of a socket pipe	$\pm 5$

**7.8.6** The construction of penstocks made of other materials shall meet the following requirements:

- a) The civil construction of penstocks made of other materials shall be carried out according to design requirements.
- b) According to the material and performance of different penstocks, follow the design and the manufacturers' requirements to do the connecting and installation of penstocks made of other materials, and carry out detection and pressure tests to ensure penstock construction quality.

## 7.9 Powerhouse

**7.9.1** Excavation and foundation treatment shall meet the following requirements:

- a) Surface powerhouse excavation should be arranged together with tailwater excavation and the excavation and foundation treatment shall meet the requirements in 6.1 and 6.3.
- b) Underground powerhouse excavation shall meet the following requirements in addition to the relevant provisions in 6.2:

- 1) Construction branch tunnels shall be reasonably arranged and permanent tunnels shall be used as much as possible as construction channels.
- 2) A pilot tunnel shall be excavated first, and its position can be decided according to the adopted construction method.
- 3) Generally, the following methods can be adopted in construction:
  - For surrounding rock of types I to III, the method of building the arch before the walls can be adopted;
  - For surrounding rock of types III to IV, the method of building the walls before the arch can be adopted; if the method of building the arch before the walls is adopted, the rock at the arch foot shall be protected and reinforced;
  - For surrounding rock of types IV to V, the ribbed wall method or ribbed arch method should be adopted, and the surrounding rock shall be reinforced first when necessary;
  - For intermediate rock, the method of excavation in benches or whole section excavation can be adopted.
- 4) During construction, construction observation shall be properly done so as to know the stress on the rock and supporting structures and the failure zone range of the surrounding rock, and to observe the displacement and distortion in the rock and the supports.
- 5) When there are adjacent parallel caverns, the rock wall shall be reinforced first, and then dug downwards.
- 6) When constructing at a cavern intersection of the powerhouse, the intersection shall be reinforced first, and the reinforcement length shall be decided according to the surrounding rock condition, and the range of control over the extension of weak surfaces. The length should not be less than 5 m.

**7.9.2** The flood-passing of a powerhouse shall meet the following requirements:

- a) Flood-passing measures shall meet the relevant requirements; besides which, measures with a reliable method and reasonable economy shall be selected through calculation, to ensure security during the flood season.
- b) If the powerhouse is used for water retaining, the underwater concrete of the powerhouse shall reach the safety elevation for flood-passing before the flood season, and all the holes related to flood-passing shall be plugged.



- c) A tailwater bulkhead shall not be used for hole plugging during the flood season. If needed, reinforcement treatment shall be done according to the plugging condition.
- d) We shall finish seepage water treatment on the construction surface of the underground powerhouse and realize a combination of blockage and discharge before the flood season comes.

**7.9.3** Powerhouse area drainage shall meet the following requirements:

- a) Powerhouse area drainage shall be constructed according to the design drawings. Before completion of the permanent drainage system, the arrangement of the temporary drainage system for the powerhouse area during construction shall be properly done.
- b) The temporary drainage water outside the powerhouse area should be directly led out of the upstream and downstream cofferdams.
- c) A permanent leakage water sump for the powerhouse should be constructed in advance before the powerhouse construction, and implemented as the main measure for powerhouse construction drainage.

**7.9.4** The layering and block-formation division of powerhouse concrete shall meet the following requirements:

- a) The principle of layering and block-formation:
  - 1) The layering and block-formation shall be done according to the factors of powerhouse structure characteristics, shape and stress, as well as equipment installation, to avoid stress concentration and cracking at the weakest parts of the structure, and to try to avoid acute angles and thin slices in the geometric shape. During block-formation, try to coordinate the construction joints and structure joints, and try not to weaken the integrity of the structure. Form, steel bars, embedded parts, concrete vibrating and the construction convenience of the second-stage concrete shall also be considered in layering and block-formation.
  - 2) The layering thickness shall be decided according to the structure characteristics and temperature control requirements. The layer thickness of foundation restraint zones should be no greater than 2 m, and the thickness can be appropriately increased above the restraint zone, but shall be no greater than 2.5 m. For parts with a large heat dissipation surface, the layering thickness can be appropriately increased according to the specific condition, but shall not be greater than 4.0 m.
  - 3) Decide the size of the block-formation area according to the concrete construction capacity and temperature control requirements, and try to reduce unnecessary construction joints.

The length-width ratio of the block should not be too large, usually less than 2.5 : 1.

- 4) For weaker parts where division is definitely needed and cracks may emerge, anti-cracking steel bars shall be arranged.
- b) The form and requirements of layering and block-formation:
- 1) The layering and block-formation of the lower part structures of the powerhouse usually adopt the form of full length, alternate joint, and full length pouring should be adopted for powerhouses of SHP stations.
  - 2) Layering should be decided depending on the baseboard, tailwater pipe, volutes, hydraulic turbine hall, generator pier and generator hall. Layering can also be considered for reference for powerhouses with tubular and impulse turbines.
  - 3) The generator unit should be taken as the individual element for longitudinal division.
  - 4) Block pouring can be used for the concrete of upstream and downstream walls, as well as left and right side walls of the lower part structures, and water sealing facilities shall be implemented for the parts with anti-seepage requirements.
  - 5) For a generator hall where the hydraulic turbine embedded parts are installed by stages, block pouring using the generator unit as an element can be used.
  - 6) The division opening shall be straight up and down or be parallel to the floor and avoid visible irregular joints on the exposed face.
  - 7) The overlap length of the alternate joint upper and lower layer pouring block is usually 1/2 to 1/3 of the pouring thickness, and should not be less than 500 mm. Measures shall be adopted to prevent the construction joint from further extending.
  - 8) Adjacent blocks shall rise uniformly, and when constructed using step joints, the elevation difference of adjacent blocks shall usually be no greater than 4 m to 5 m.
  - 9) The side walls and roof board of the volute should not be poured at one time.

**7.9.5** The construction of reinforced concrete volute and tailwater pipe forms shall meet the following requirements:

- a) Wood forms should be used for volutes, circular conical tubes of the tailwater pipe and elbows. The form can be made of steel wood or other materials as a substitute for the diffuser section of

the tailwater pipe, but there shall be feasible and detailed measurements at the connecting part of the steel and wood forms to make sure the deviation during form installation and concrete construction shall be no greater than the requirements in Table 47. For the straight section of the tailwater pipe after concrete pouring, concrete, brick or masonry forms can be used instead of steel wood forms. For the roof board of the diffuser section of the tailwater pipe, when preparing the hoisting condition, precast inverted T-shaped beams should be used for hoisting construction.

- b) Wood forms shall be produced in the processing factory, avoiding exposure to the sun and rain, and the form length shall be decided according to form size and production capacity, hoisting, transportation, and installation and construction capability. Production of the entire body or in subsections can be adopted, and priority should be given to choosing the former. The conical body of the volute can be produced according to a 1/4 circular conical surface. The allowable error in form production shall meet the form design requirements, and should not be greater than the requirements in Table 48.
- c) Setting up of the tailwater pipe form can be done using a graphical method, numerical method or by form enlargement.
- d) Collision and distortion shall be avoided in form transportation, and reinforcement measures shall be taken if the form size is large.
- e) The installation of the form for the conical body of the volute shall be carried out after the installation of the stay ring, and the upper opening of the form must be closely connected to the lower part of the inter-connected body.
- f) When the form is in position, the corresponding precision with the horizontal and vertical axis of the generator unit as well as the installation elevation shall be rechecked, and the installation error shall be no greater than the requirements in Table 47.

**Table 47 Allowable deviation of volutes and tailwater pipe form installation** Unit: mm

No.	Deviation item	Volutes	Tailwater pipe
1	Form evenness; elevation difference of adjacent face slab	3	3
2	Local unevenness	5	5
3	Axis replacement	± 5	± 5
4	Form elevation	± 5	± 5
5	Section size	± 10	± 10
6	Embedded parts		5
7	Size and position of pre-formed holes	5	10
<b>NOTE</b> Volute internal size means the size of the radial section.			

**Table 48 Allowable error for volutes and tailwater pipe form production** Unit: mm

No.	Error item	Volutes	Tailwater pipe
1	Form length and width	± 5	± 5
2	Width between adjacent board surfaces	3	2
3	Local unevenness	5	3
4	Face slab crack	2	2
<b>NOTE</b> Local unevenness means the deviation of a curved form from the design dimensions; the error is checked using a 2 m straight ruler for a flat form.			

g) Form removal shall meet the requirements in 6.5.1.6.

**7.9.6 Concrete construction of the lower parts shall meet the following requirements:**

- a) Concrete construction of the lower parts shall mainly be determined by concrete-pouring, and coordinated with electromechanical installation. Upper concrete construction shall be determined by electromechanical installation and concrete-pouring is a secondary consideration.
- b) The equipping of the main items of machinery for concrete transportation and pouring, as well as the productivity they may achieve, shall be decided according to the powerhouse characteristics, such as complex structures shape, if there are many embedded parts and much auxiliary work.
- c) The temperature control measures for the lower part concrete shall meet the requirements in 6.5.3.13, 6.5.3.14 and 7.3.6.
- d) When the air temperature suddenly drops during the construction of the lower part concrete, the protection of the exposed surfaces of the poured concrete structures shall be strengthened, and the poured holes shall be closed off during the low temperature season.

**7.9.7 Upper part concrete construction shall meet the following requirements:**

- a) Concrete construction of the upper part should be mainly based on mechanical and electrical installation, and civil construction shall be coordinated. Upper part structures shall be finished before crane operation.
- b) An erection bay should be constructed in advance of the main generator room, and external equipment should be used to hoist the crane into place before capping, so as to create conditions for the testing and pre-assembly of the components of the main units.
- c) The parts related to the first stage power generation shall be constructed in advance.

- d) Hoisting of reinforced concrete beams, plates, and bent frames shall be carried out according to the requirements in 6.7.
- e) When the skeleton method self-supporting or load bearing framework is adopted in construction, then strength design and stiffness checks shall be done for the skeleton and the framework to ensure sufficient stability and construction convenience. During construction, the camber shall be set according to design requirements.

**7.9.8** Powerhouse second stage concrete construction shall meet the following requirements:

- a) Powerhouse second stage concrete shall meet the requirements in 6.5 as well as the following requirements:
  - 1) The strength of the second stage concrete should be 5 MPa greater than the strength of the first stage concrete.
  - 2) The aggregate of the second stage concrete shall not be greater than 1/4 of the thickness of the smallest structure of the second stage concrete, or 1/2 of the smallest clear spacing between the steel bars (or embedded parts).
  - 3) When the smallest structure thickness of second stage concrete is less than 300 mm, connecting steel bars shall be installed at the smallest structure of the second stage concrete next to the former first stage concrete, and be used to fix the embedded parts of the second stage concrete.
  - 4) Before the pouring of second stage concrete, all the embedded parts shall have been buried according to design and relevant requirements, the pouring bin surface having been effectively treated according to regulations.
  - 5) During second stage concrete pouring, the concrete placement shall not impact the embedded parts and formwork, and any impact on the steel bars should be avoided. Concrete vibrating mechanical dies shall not vibrate within a range equal to the distance from the formwork, embedded parts and supports of 1/2 of the effective vibrator radius, and shall not touch the embedded parts, water-stop, steel bars connected with the water-stop. For parts where a vibrator is not usable, compaction shall be done manually.
- b) Powerhouse second stage concrete construction shall pay attention to the following problems:
  - 1) When the work of form installation and of tying up steel bar overlaps at times with that of embedded parts installation, then the protection of the embedded parts shall be attended to.

- 2) After powerhouse roof capping, the concrete transportation and the placing method shall be properly dealt with during the second stage concrete pouring, and concrete transportation passing through areas above any units already in operation or being installed shall be avoided.
- 3) The installation of stay rings shall be carried out after the concrete construction of the tail-water pipe level, so that the hydraulic turbine hall, generator piers and generator hall can be constructed in sequence.
- 4) Taper back lining, runner chambers and stay ring embedded parts should be installed at one time, for the convenience of precise control of the entire installation, and the second stage concrete pouring should also be done at one time.
- 5) For places where the second stage concrete cannot be properly combined with the first stage concrete, cement grouting for joint surfaces shall be carried out when the second stage concrete reaches the design strength, and during grouting, and lifting of the embedded parts caused by grouting pressure shall be avoided.
- 6) For the second stage concrete at narrow sections or places that are not easily reached, the method of pre-packed aggregate grouting concrete can be adopted for construction, and this method shall meet the requirements in 6.5.3.20.
- 7) The size of the reserved second phase concrete shall meet the space requirement for installation of the unit and embedded parts.

## 8 Installation of hydro mechanical structures

### 8.1 Basic requirements

8.1.1 The technical documentation shall meet the following requirements:

- a) Before the installation of hydro mechanical structures, the following documents shall be prepared:
  - Manufacturing documents for the hydro mechanical structures; installation drawings and technical documents;
  - Product quality certifications;
  - Layout drawings of the hydraulic structures and drawings of measurement points.

- b) The installation of hydro mechanical structures shall comply with the design drawings and relevant technical documents. If there is any modification, a notification of modification or written consent signed by the design department shall be provided.

**8.1.2** The materials used shall meet the following requirements:

- a) The materials used in the installation of hydro mechanical structures shall meet the requirements in the design drawings. The properties shall meet the requirements of relevant current standards. The product shall have quality certification; if there is no certification or the mark number is unclear, the material shall be rechecked. The material can only be used when it has passed the rechecking.
- b) Material used in welding shall have quality certifications. Indices such as chemical composition, mechanical properties and diffusible hydrogen content shall meet the requirements.

**8.1.3** Datum points and measuring tools shall meet the following requirements:

- a) Datum points and installation control points which are used in the elevation survey and installation along the axis shall all be obvious, firm and easy to use. The survey department shall explain and provide the sketch of point positions to the installation department on site.
- b) The accuracy of the steel rulers and measuring apparatus used in installing hydro mechanical structures shall meet the following requirements:
  - The steel ruler's accuracy shall be 1/10 000;
  - J2 Theodolite;
  - S3 Level Gauges.
- c) The measuring tools and instruments used in the hydro mechanical structure's installation shall be sent to a legal calibration department and checked before use.

**8.1.4** The connection of hydro mechanical structures shall meet the following requirements:

- a) The welding of the hydro mechanical structures' important joints such as onsite splicing weld joints of sectional sluice gates, onsite longitudinal joints and circular seams of penstocks shall be the same as for similar weld joints in manufacturing and shall comply with the corresponding standards.

- b) For permanent bolted connections, the manufacturing of bolt holes and bolts, as well as bolt tightening shall meet the relevant requirements.

**8.1.5** Hydro mechanical structures' anti-corrosion shall meet the following requirements:

- a) Surface pre-treating, paint coating and thermal spraying of hydro mechanical structures shall comply with the requirements of the design drawings and shall be completed by the manufacturer. Coating of the installation weld joints with paint within a range of 100 mm to 200 mm on both sides shall be carried out after the weld joints have passed quality checks.
- b) Coating shall not be done for work pieces whose surface temperature is lower than 3 °C above the dew point or when the relative humidity is greater than 85%. If there are separate stipulations from the paint manufacturer, then these shall be followed during execution.
- c) The quality check of the paint coating and metal coating shall meet the relevant requirements.

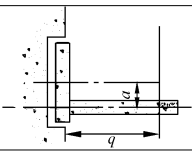
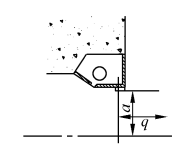
**8.2** Sluice gates and embedded parts

**8.2.1** Installation of embedded parts shall meet the following requirements:

- a) Anchor plates (bolts) and anchor bars embedded in the first-stage concrete shall be manufactured according to design drawings. Anchor plates (bolts) shall be marked and fixed on the formwork according to construction drawings. Anchor plates (bolts) shall be closely attached to the formwork. The position of the embedded anchor plates (bolts) and anchor bars shall be checked and verified before the concrete is poured.
- b) Before the installation of embedded parts, sundry items such as formwork in the gate slots shall be cleared away. The interface between the first-stage and second-stage concrete shall be scabbled. In the second-stage concrete, the section size and the position of the embedded anchor slabs, bolts and bars shall meet the design drawing requirements.
- c) When installing the embedded parts of plane gates, the allowable error shall meet the requirements in Table 49.
- d) The installation of embedded parts for plane gates shall meet the requirements in Table 49 and the staggered displacement at the joints of the main track bearing face shall be no less than 0.2 mm. The joints shall be processed to have gentle slopes. The main track bearing faces on both sides of the sluice hole shall be on the same surface. The flatness tolerance shall meet the requirements of Table 50.



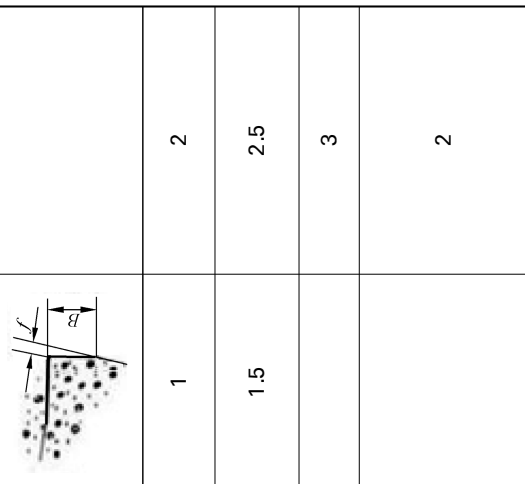
Table 49 Allowable deviation for installation of the embedded parts of plane gate grooves Unit: mm

No.	Description of embedded parts	Bottom sill	Lintel	Main track		Side track	Reversal Track	Side water stop base Plate	Angle bead and side Track	Breast wall			
				Processed	Unprocessed					Used as water stop	Not used as water stop	Upper part	Lower part
1	Sketch 	$\pm 5$	$+2$ $-1$	$+2$ $-1$	$+3$ $-1$	$\pm 5$	$+3$ $-1$	$+2$ $-1$	$\pm 5$	$+5$ $-0$	$+2$ $-1$	$+8$ $-0$	$+2$ $-1$
2	Sketch 	$\pm 5$	$+2$ $-1$	$+3$ $-1$	$+3$ $-1$	$\pm 5$	$+3$ $-1$	$+2$ $-1$	$\pm 5$	$+5$ $-0$	$+2$ $-1$	$+8$ $-0$	$+2$ $-1$
3	Elevation	$\pm 5$											



Unit: mm

Table 49 (continued)

8	Surface distortion $f$	Sketch								
			1	0.5	1	2	2	2	1	
	Surface width within the working range	$B < 100$	1	1	1	2	2	2	1	2
	Surface width within the working range	$B = 100 \sim 200$	1.5	1	2	2.5	2.5	2.5	1.5	2.5
		$B > 200$	2	1	2	3	3	3	3	3
	Allowable additional deviation outside of the working range			2						2

- NOTE 1  $L$  indicates width of wide gate;
- NOTE 2 Members should be measured at least one point per meter;
- NOTE 3 The breast wall is connected with the lintel at the lower part;
- NOTE 4 The height of the gate groove in the working range is the height of the orifice in the static water condition, and is the height of the pressure-bearing main track under dynamic water condition;
- NOTE 5 If the side wheel is a pre-loaded resilient device, the side rail deviation shall be specified according to the drawing;
- NOTE 6 Dislocation of the jointing part should be processed into gentle slope;
- NOTE 7 The directions of allowable deviation of embedded parts installed in both the left and right gate grooves should be kept as consistent as possible.

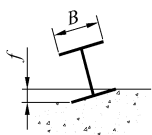
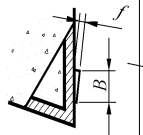
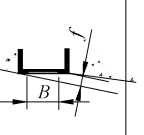
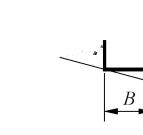
Table 50 Flatness tolerance of main track bearing faces

Main track length(mm)	Tolerance(mm)
≤1 000	0.4
>1 000~2 500	0.5
>2 500~4 000	0.6
>4 000~6 300	0.8
>6 300~10 000	1.0

- e) The allowable installation error of the embedded parts for lift-lie plain gates shall meet the following requirements:
- The installation deviation for the main track turning radius shall be no greater than 1/1 000 of the turning radius and shall be no greater than 2 mm. The allowable error of the arc centre position shall be no greater than 2 mm.
  - The main track's vertical flatness error shall meet the drawing requirements. If there is no requirement, it shall be less than 2 mm.
  - The water stop seat plate should be higher than the concrete surface by 3 mm to 5 mm, and the allowable flatness error of shall be no greater than 2 mm.
- f) For Tainter gate hinges, the installation deviation for the centre positions of the foundation bolts shall be no greater than 1 mm.
- g) The installation tolerance or maximum deviation of Tainter gate embedded parts shall meet the requirements of Table 51.

Table 51 Allowable deviation for installation of embedded parts of the radial gate

Unit: mm

No.	Embedded parts		Bottom sill	Lintel	Side Water Stop Base Plate		Lateral wheels guide plate		
	Sketch				Submerged	Immersed			
1	Distance		± 5	+ 2 - 1					
2	Elevation		± 5						
3	Distance from lintel centre to bottom sills surface, $h$			± 3					
4	For centreline of orifice, $b$	In the working range	± 5		± 2	+ 3 - 2	+ 3 - 2		
		Out of working range			- 4 - 2	+ 6 - 2	+ 6 - 2		
5	Elevation difference from one end to the other end of the working surface.	$L \geq 10\ 000$	3						
		$L < 10\ 000$	2						
6	Flatness of working surface		2	2	2	2	2		
7	Dislocation of joints on the working surface		1	0.5	1	1	1		
8	Curvature radius of the centre line of a lateral water stop seat plate and a lateral wheel guide plate				± 5	± 5	± 5		
9	Working surface distortion, $f$	Sketch							
			Surface width within the working range	$B < 100$	1	1	1	1	2
				$B = 100 \sim 200$	1.5	1.5	1.5	1.5	2.5
		$B > 200$		2		2	2	3	
Allowable additional deviation out of the working range					2	2	2		

**NOTE 1**  $L$  is the width of the sluice gate.

**NOTE 2** Generally, the lintel is fixed at last during the installation, so the position of the lintel should be adjusted according to the actual position of the gate leaf.

**NOTE 3** Working range means the orifice height.

**NOTE 4** Members should be measured at least one point per meter.

- h) For Tainter gates which run under high water head with throat type slots, the maximum deviation of the distance between the side track's water stop seat base surface centre line and the sluice hole centre line is  $\pm 2.0$  mm; the maximum deviation of the side track's water stop seat base surface curvature radius is  $\pm 3.0$  mm, the deviation direction shall be in accordance with the deviation direction of the gate leaf outer cambered surface's curvature radius; the maximum deviation of the gap between the side track's water stop seat base surface and the gate leaf outer cambered surface shall be no greater than 1.5 mm; if the down the hole side water stop base is made of stainless steel, the combination of dislocation shall be 0.5 mm and shall be polished.
- i) When the Tainter gate hinge's steel beam is installed independently, the maximum deviation of the steel beam centre's travel, elevation and the distance to the centre line of the sluice opening is  $\pm 1.5$  mm. The schematic diagram for tilt of the hinge's steel beam is shown in Fig. 1. The deviation of the horizontal projection size shall be controlled to ensure that the deviation of  $L$  shall be no greater than  $1/1\ 000$  of  $L$ .

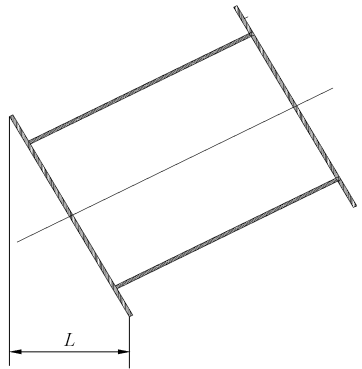


Fig.1 Schematic diagram for tilt of the hinge's steel beam

- j) The maximum deviation of the horizontal steel lining's elevation is  $\pm 1.5$  mm. The maximum deviation of the distance between the lateral steel lining and the sluice hole centre line is  $-2$  mm to  $+6.0$  mm. The maximum surface flatness tolerance is 4.0 mm. The maximum perpendicularity tolerance is  $1/1\ 000$  of the height and shall be no greater than 4.0 mm. The staggered displacement of composite surfaces shall be no greater than 2.0 mm.
- k) When embedded parts have been well adjusted, the adjusting screws, anchor slabs and bolts shall be firmly welded as per the requirements of the design drawings to make sure that the embedded parts have no distortion or displacement in the process of second-stage concrete casting.
- l) Butt joint misalignment on the working surfaces of embedded parts shall be treated to form gentle slopes. Weld scars and weld reinforcement on the flow-passing surfaces and working surfaces shall be evened out and polished, while the weld pits shall be repaired and polished.
- m) The installed embedded parts shall be poured with second phase concrete in good time after

passing the check. If the time interval is 5 days or more, or the embedded parts are collided, they shall be rechecked before being poured with concrete. The pouring height of the second stage concrete should not exceed 5.0 m at one time. During pouring, attention shall be paid to prevent the impacting of the embedded parts and formwork, and measures shall be taken to tamp the concrete, and secondary stage concrete shall be prevented from segregating, formwork shifting and leakage.

- n) After form stripping of the second-stage concrete, the embedded parts shall be rechecked and the results shall be properly recorded. At the same time, check the size of the concrete structures and remove the remaining steel bars and sundry items to avoid affecting the operation of the sluice gates.
- o) Before retaining water, trial installation of all bulkhead gate slots and shared gate slots shall be properly done.

#### 8.2.2 Installation of plane sluice gates shall meet the following requirements:

- a) Before the installation of integrated gates, the gate size shall be rechecked according to the design drawings and meet the relevant requirements in those documents.
- b) When the sectional sluice gates have been assembled, not only the gate size shall be rechecked according to the relevant requirements in this document, but the following requirements shall also be met: if the segments are bolted together, the bolts shall be uniformly tightened and the amount of rubber compression between segments shall meet the design requirements; if the segments are welded together, a qualified welding process shall be adopted, and both the welding and checking of welding quality shall meet the relevant welding requirements in this document. Measures shall be taken while welding to control distortion.
- c) The size of the filling valves shall meet the requirements of the design drawings, and the guide mechanism shall be flexible and reliable. The contact between the seals and seat valves shall be uniform, and shall meet the water stopping requirements.
- d) The rubber water seal's physical and mechanical properties shall meet the relevant requirements.
- e) The position of the rubber seal screw holes shall be consistent with those of the gate leaves and the seal's press plates. The hole diameter shall be less than that of the bolts by 1.0 mm and the holes shall be drilled with special hollow drills. The holes shall not be treated by scalding. When the bolts have been uniformly tightened, their end sections shall be lower than the rubber water seal's free surface by at least 8.0 mm.
- f) The rubber seal surface shall be smooth and straight. Rubber-plastic compound seals shall be transported flat and shall not be rolled or folded. The maximum deviation in thickness is  $\pm 1.0$  mm.

The allowable error for other section sizes is 2% of the design size.

- g) The rubber seal joints should be cured by vulcanisation and there shall be no misalignment, unevenness or porosity around the joints. If adhesives are used at normal temperature, the rubber seal tensile strength shall be no less than 85% of the tensile strength.
- h) When the rubber seals have been installed, the maximum deviation in the distance between water stop centres on two sides and the distance from the top water stop to the bottom water stop's base is  $\pm 3.0$  mm. The flatness tolerance of the water stop surface is 2.0 mm. When the sluice gates are working, the amount of rubber seal compression shall meet the requirements of the design drawings. Light penetration inspection or water flushing tests shall also be conducted.
- i) Static balance tests shall be done for plane sluice gates. The test method is as follows: lift the sluice gate 100 mm above the ground, measure the tilt displacement of the left side, the right side, and the upstream and downstream sides using the centre of an idler wheel or slideway. Generally, the tilt displacement of a single hanging point plane gate shall not exceed 1/1 000 of its height and shall also be no greater than 8.0 mm. The tilt displacement of a plane sprocket gate shall not exceed 1/1 500 of its height and shall be no greater than 3.0 mm. If the tilt displacement exceeds the requirements above, counterbalance weights shall be added to the gate to balance the weight.

**8.2.3** Tainter gate installation shall meet the following requirements:

- a) For cylindrical trunnion, spherical trunnion and other types of trunnions, the tolerance or the maximum deviation for installation of trunnion support shall meet the requirements of Table 52.

**Table 52** Installation tolerance or maximum deviation of tainter gate hinged bearings

No.	Items	Tolerance or maximum deviation (mm)
1	Distance from hinged bearing centre to sluice hole centre line	$\pm 1.5$
2	Mileage	$\pm 2.0$
3	Elevation	$\pm 2.0$
4	Axis hole tilt of hinged bearing	$\pm 1/1\ 000$
5	Axiality of two hinged bearings axes	$\pm 1.0$
<b>NOTE</b> Axis hole tilt of hinged bearing means tilt in any direction.		

- b) When a sectional Tainter gate leaf has been assembled, each size shall be rechecked according to the design drawings and the results shall meet the relevant requirements of this document. If the segments are welded together, a qualified welding process shall be adopted, and both the welding and checking of the welding quality shall meet the relevant welding requirements of this document. If the segments are bolted together, the bolts shall be tightened and checked according



to the relevant requirements for bolting.

- c) The installation of Tainter gates, support arms and supporting trunnion bearing shall meet the following requirements:
- 1) If the junction plates at the two ends of a support arm need to be welded when installing, effective measures shall be taken to reduce any distortion during the welding process to ensure the junction plates and main beams or hinges are properly connected.
  - 2) The shear plate shall be tightly welded to the top of the connecting plate.
  - 3) Connecting bolts shall be fastened and inspected in accordance with the relevant provisions for bolted connections. The connecting surfaces shall cling to each other with more than 75% of the area, and the maximum clearance at the edge shall not be greater than 0.8 mm.
  - 4) The maximum deviation of  $R$ , the radius of the Tainter gate's outer surface whose centre is the trunnionaxis's centre, shall meet the following requirements: for Tainter gates with their upper portion exposed, the maximum deviation shall be  $\pm 8.0$  mm and the difference between the radius on two sides shall be no greater than 5.0 mm. For submerged Tainter gates, the maximum deviation shall be  $\pm 4.0$  mm and the relative difference between the radius on two sides shall be no greater than 3.0 mm. For Tainter gates which operate under high water head with throat type slots, including eccentric-hinge Tainter gates and hydraulic expansion seal Tainter gates, the maximum deviation shall be  $\pm 3.0$  mm and the deviation direction shall be in accordance with the deviation direction of the seal seat base surface's curvature radius on the side track. The maximum deviation of the gap between the side track's seal seat base surface and the gate leaf outer cambered surface shall be no greater than 3.0 mm, and meanwhile the relative difference between the radiuses on two sides shall be no greater than 1.5 mm.
  - 5) The rubber seal quality shall meet the relevant requirements of national or industry technical standards. Top and lateral waterstop installation shall meet the relevant requirements in 8.2.2.

#### 8.2.4 Sluice gate tests shall meet the following requirements:

- a) After installation of the sluice gates, entire travel opening and closing tests shall be performed when there is no water. Before the tests, careful inspection shall be done to see if the hooks can be freely and reliably unhooked, if the gate leaf can go up and down easily along the entire travel and if the seal has no leakage at the lowest position. At the same time, all the sundry items on the gate leaves or in the grooves shall be cleared away. The suspender connection shall be checked as well. During operation, the rubber seals shall be lubricated by water. If conditions permit, opening and closing tests in dynamic water shall be performed for the working gates, and dynamic water closing tests shall be performed for the emergency gates.

- b) In the opening and closing process for the gate, the working condition of the movable parts (including roller, trunnion, upper and bottom pintles) shall be checked, and it shall be checked whether the gates are blocked during the lifting or moving process, whether the hoisting equipment is synchronous on both sides, and whether the rubber seals are damaged.
- c) When the sluice gates are all in the working position, light penetration or other methods shall be used to check the amount of rubber seal compression. There shall be no light penetration or gaps. If the seal is on the upstream side, it shall be checked after supporting devices have been connected to the tracks.
- d) When the sluice gates are operated under design water head, the water leakage of the seal per meter per second shall be no greater than 0.1 L/s.

**8.2.5** Installation of the trash rack and embedded parts shall meet the following requirements:

- a) The embedded parts' installation tolerance or the maximum deviation of a movable trash rack shall meet the requirements of Table 53.
- b) For the trash rack and embedded parts which are installed slantwise, the allowable error of their tilt angle is  $\pm 10$ .
- c) When installing a fixed trash rack and its embedded parts, each beam's working surface shall be in the same surface and the difference between two working surface's highest points or lowest points shall be no greater than 3.0 mm.
- d) When the trash rack has been put into the slot, lifting tests shall be performed to check whether there is any blockage in the slot and to check whether the trash rack movement and joints are reliable.
- d) For trash racks which use cleaning machines to remove trash, the structure and embedded parts shall meet the operating requirements for the cleaning machines.

**Table 53** Allowable error for the movable trash rack's embedded parts installation

Unit: mm

No.	Items	Ground sill	Main track	Opposing track
		Allowable error		
1	Mileage	$\pm 5.0$	—	—
2	Elevation	$\pm 5.0$	—	—
3	Elevation difference between two ends of the working surface	3	—	—
4	Centre line of trash rack's grooves	—	+ 3.0 - 2.0	+ 5.0 - 2.0
5	Distance from bay centre line	$\pm 5.0$	$\pm 5.0$	$\pm 5.0$

### 8.3 Headstock and hoisting equipment

8.3.1 The gate travel's wheel track installation shall meet the following requirements:

- a) If the steel wheel track has any distortion such as bending or distortion, the shape of the wheel track shall be repaired according to the following requirements. The track can be installed only after it is qualified.
- 1) Steel wheel track's lack of straightness on the front and lateral sides shall be no greater than  $1/1\ 500$  of the total length and shall be no greater than 2 mm;
  - 2) The two end faces of the steel track shall be straight and the tilt displacements shall be no greater than 1 mm.
- b) The deviation of the distance between the track foundation bolts and the track centre line shall be no greater than  $\pm 2$  mm. When the track has been installed, 2 to 5 threads of the screw shall be exposed.
- c) Allowable installation error of the tracks shall meet the requirements of Table 54.

**Table 54 Allowable installation error for wheel tracks**

Unit: mm

No.	Item	Allowable error	Note
1	Offset between track's actual centre line and design centre line: $L \leq 10\ 000$ $L > 10\ 000$	2 3	Track's design centre line shall be measured according to the headstock gear's hoisting centre line, dam axis or power house centre line
2	Track gauge: $L \leq 10\ 000$ $L > 10\ 000$	$\pm 3$ $\pm 5$	—
3	Track's lengthways straightness	$1/1\ 500$ of member length and shall be no greater than 10	—
4	Track crosswise inclination	$1/100$ of track width	Measure the ends and the middle of each track
5	Relative elevation difference of two tracks in the same section	$L/800$ and shall be no larger than 10	—
<b>NOTE</b> L—Track gauge.			

d) The wheel track joints shall meet the following requirements:

- 1) Joint misalignment on the left, right and front of the wheel track shall be no greater than 1 mm.

- 2) The joint positions of two parallel wheel tracks shall be staggered, and the staggered distance shall not be equal to the length of the wheelbase (between the front and rear wheels) of the lifting device.
- 3) The gap between joints shall be between 1 mm and 3 mm. The gap between expansion joints shall meet the requirements of the drawings and the deviation shall be no greater than  $\pm 1$  mm.

**8.3.2** The assembly of the hoisting equipment shall meet the following requirements:

- a) Generally, the equipment shall be assembled in the factory, but large size equipment which is difficult to assemble in the factory can be assembled on the construction site.
- b) All the components and parts shall pass the quality tests. Purchased parts and co-produced parts can only be assembled when they have quality certifications.
- c) Tighten all the tightening screws when all the parts are in the right position. Spring washers shall be in complete contact with the supporting surfaces of the screw nuts and other parts.
- d) Loose keys shall be replaced to prevent cracking of the shell. It is forbidden to put gaskets in the key slots.
- e) The hinged shafts of the brakes shall not be rusted and blocked and the gap between the brake wheel and the brake shoe shall meet the relevant requirements.
- f) For the quick hoist, the thrust face of the centrifugal governor shall maintain periphery clearance evenly, and the initial clearance value shall be 0.75 mm.
- g) The friction surface between the brake and centrifugal governor shall have no oil stains. The contact area shall be flat with even loading, and shall not be less than 75% of the whole friction surface.
- h) Before adding oil, the speed reducer shall be cleaned and checked. The quality of the lubricant oil used in the reducers shall meet the manufacturing design requirements. The oil level shall be in accordance with the oil scale calibration. If there is no oil scale, the oil level shall be neither lower than the depth of the gearwheel's lowest tooth, nor too high. The reducer shall run freely and its oil seal and joint face shall have no oil leakage when running.
- i) Both the screw threads of the bolts which are used to fix the steel wire ropes, and the threads of the steel rope drum bolt holes shall be undamaged. Bolts shall have anti-loosening devices as well.
- j) Anti-corrosive grease shall be coated on the surfaces of steel wire ropes, and the ropes shall

have no defects such as corrosion, hard bends, twists or squashed parts. The types and lengths of the ropes shall meet the drawing requirements, and the ropes shall have quality certification. If there is no quality certification, a 1 500 mm length of rope shall be cut to perform a single filament tensile strength test in order to calculate the rope's total tensile strength. Only when the strength meets the drawing requirements can the steel rope be used.

- k) When winding multi-layer steel wire ropes on a steel rope drum, the rope shall be wound on the steel rope drum in an orderly manner, layer by layer, and shall not be squeezed or disordered.
- l) The main parts of the overload device's load indicator shall be debugged before leaving the factory. For a spring lever type overload device, the lever shall move freely and the spring shall be checked by a stiffness test, the data from which shall be provided to the user in the technical documents for the convenience of onsite adjustment. When using a load indicator-electronic scale, the lever's pressure centre line shall pass through the sensor's axis and horizontal thrust shall be avoided. The sensors shall be packed separately when leaving the factory.
- m) When assembling the wheels, their positions shall be symmetrical to the bearing box's sub-plate. The bearing box's two supporting surfaces shall be on the two vertical surfaces which are parallel to the wheel centre, and the parallel deviation shall be no greater than 0.09 mm. The bearings shall be filled with grease.
- n) Electrical equipment installation shall meet the relevant requirements of the current national standards.

**8.3.3** Installation of the fixed hoisting rope drumgear unit shall meet the following requirements:

- a) After arrival, the equipment shall be accepted on site. Only after the parts have passed the field acceptance can they be installed.
- b) The speed reducer shall be filled with new lubricant oil when it has been cleaned, and the oil level shall be neither lower than the depth of the high speed gearwheel's lowest tooth, nor higher than twice the tooth depth. The oil seal and joint face shall have no oil leakage.
- c) Check if the embedded position of the foundation bolts and bolt's extension length meet the installation requirements.
- d) Check the rope drumgear's platform elevation. The deviation shall be no greater than  $\pm 5$  mm and the horizontal deviation shall be no greater than 0.5/1 000.
- e) The rope drumgear installation shall be aligned according to the hoisting centre line. Both the deviations of longitudinal and crosswise centre lines shall be no greater than  $\pm 3$  mm.
- f) When the hoisting point is at the lower limit, the number of steel wire rope loops on the steel

rope drum shall be no less than 4, of which 2 loops are kept for fixation and the other 2 loops are kept for safety. When the hoisting point is at the upper limit, the steel wire rope shall not be wound outside of the rope drum's coiling block's rope race.

- g) The steel wire rope's limiting guide angle shall be no greater than  $\pm 6^\circ$ ; for multilayer winding, the steel wire angle shall be between  $0.5^\circ$  and  $2.5^\circ$ ; the angle of return of each layer shall be between  $0.5^\circ$  and  $2.5^\circ$ .
- h) For rope drumgear with double lifting points which use tandem double rope drum, the deviation of the distance between hanging points shall be less than  $\pm 3$  mm. Whatever position the sluice gate is in the gate groove, the horizontal deviation of the sluice gate's lifting lug centre line shall meet the design requirements. If it exceeds the allowable design value, the rope drumgear shall give an alarm indication or have a correction function.
- i) Steel wire rope shall be wound in an orderly manner on the steel rope drumlayer by layer. The rope shall not be squeezed or overlapping, and shall not skip slots or be in a mess.
- j) For rope drumhead stock gear with a rope guider, make sure it can fold back smoothly.
- k) The indicating accuracy of a gate position indicating device shall be no lower than 1%. The device shall have an adjustable set value limit, main circuit automatic breaking function and alarm function. The instrument display shall have correction indications and a zero setting function. Stroke testing components shall have damp-proofing and anti-interference functions.
- l) The system accuracy of the load control device shall be no less than 2% and the sensor's accuracy shall be no less than 0.5%. When the load reaches 110% of the gate's rated lifting force, the load control device shall cut off the main circuit automatically and send out an alarm. The instrument display shall meet the requirements of the rope drum gear capacity. If the rope drumgear has two or more hoisting points, the instrument shall be able to display each point's hoisting force respectively. The sensor and its circuit shall have damp-proofing and anti-interference properties.
- m) Lubricant oil used in rotating parts such as reducers, open gear pairs, bearings, and hydraulic brakes shall be well selected according to the temperature and working conditions.
- n) Electrical equipment installation shall meet the relevant requirements.

#### 8.3.4 Hydraulic hoist installation shall meet the following requirements:

- a) After arrival at the site, the equipment shall be unpacked, checked and accepted first. Only when the parts have passed the inspection can they be installed.

- b) The distance between the crosswise centre line of the hydraulic hoist rack and the actual hoisting centre line shall be no greater than  $\pm 2$  mm. The elevation deviation shall be no greater than  $\pm 5$  mm. For hydraulic hoist with double lifting points, the supporting surface's elevation difference shall be no greater than  $\pm 0.5$  mm.
- c) The composite surface of the rack steel beams and thrust supports shall not have any fissures longer than 0.05 mm, and any localised gaps shall be no greater than 0.1 mm. The depth shall be no greater than 1/3 of the composite surface's width. The cumulative length shall be no longer than 20% of its perimeter. The horizontal deviation of the thrust support's top surface shall be no greater than 0.2/1 000.
- d) When hoisting the hydraulic cylinder, measures shall be taken to prevent distortion. Determine the number of supporting and hoisting points according to the hydraulic cylinder's diameter, length and weight. All the supporting points shall be supported by crossers.
- e) Pipelines installed in the field shall be entirely flushed by recycle oil, and the flushing speed should be great enough to generate turbulent flow. The filter screen's filtering accuracy shall be no less than 10  $\mu\text{m}$ , and the washing time shall be no less than 30 min.
- f) Adjust the upper and lower limiting points and water filling contacts to ensure the height indicating device can display the correct position of the sluice gate.
- g) The type, amount and level of hydraulic oil which is filled in the field shall meet the design requirements and the hydraulic oil's filtering accuracy shall be no less than 20  $\mu\text{m}$ .

**8.3.5** The installation of mobile hoists such as trolley gate hoists, bridge crane and gantry gate hoists shall meet the following requirements:

- a) After assembly, the bridge frame and gantry shall meet the following requirements:
  - 1) The girder mid span camber  $F = (0.9 \sim 1.4) L / 1\,000$  and the maximum camber shall be controlled to be within  $L/10$  at the middle of the span (Figs 1 and 2). The lifting degree of the cantilever's end  $F_0 = (0.9 \sim 1.4) L_1 / 350$  (or  $L_2$ ). The camber and lifting degree shall be measured without the influence of sunlight and temperature.
  - 2) The girder's horizontal bending  $f \leq L / 2\,000$ , but the maximum value shall not exceed 20 mm (Fig 2). It shall be measured at the webplate which is about 100 mm from the upper cover plate.

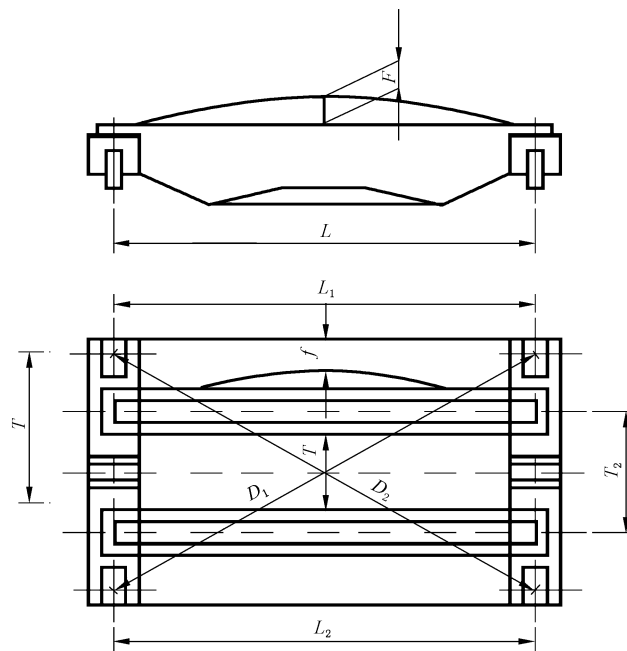


Figure 2 Schematic diagram of main beam upper camber and horizontal bending for the movable headstock gear

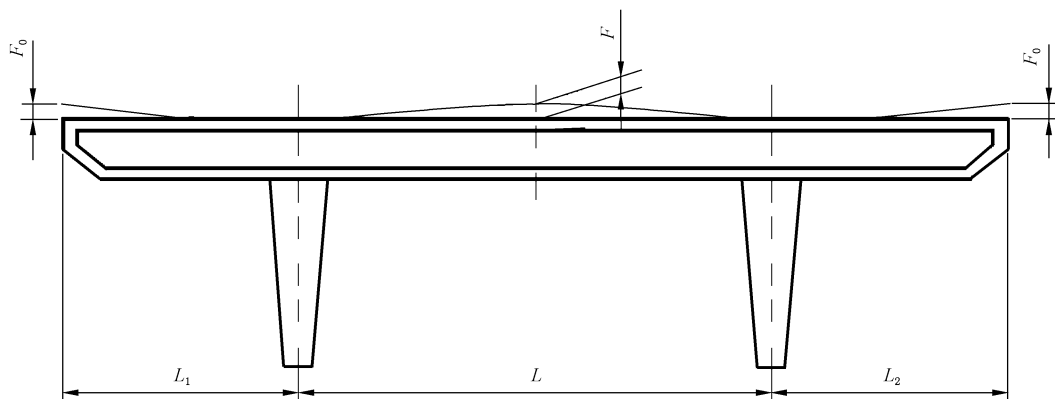


Figure 3 Schematic diagram of main beam upper camber for the movable headstock gear

- 3) The horizontal deflection of the girder's upper cover plate  $b \leq B/200$  (Fig 4). It may be measured at the ribbed slab before the girder has been put on the track.
- 4) The girder web's vertical deflection  $b \leq H/500$  (Fig 5). It shall be measured at the long ribbed slab.
- 5) The bridge frame's diagonal difference  $|D_1 - D_2| \leq 5 \text{ mm}$  (Fig 2).
- 6) The waviness of the girder's main webplate, which is checked by a 1 m levelling ruler, shall



be no greater than  $0.7\delta$  within a distance of  $1/3H$  from the upper cover plate and shall be no greater than  $1.0\delta$  at other locations. (Fig 6).

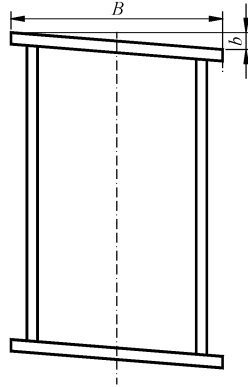


Figure 4 Schematic diagram for lateral deviation of main beam upper cover plate for the movable headstock gear

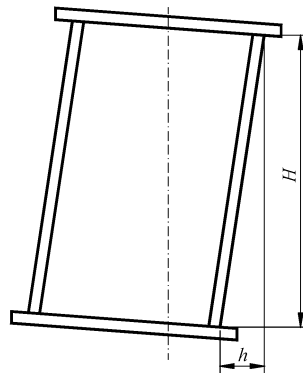


Figure 5 Schematic diagram for vertical deviation of main beam web for the movable headstock gear

- 7) The degree of verticality of the support leg in the span direction  $h_1 \leq H_1/2000$  (Fig7) and the direction of tilt shall be symmetrical with each other. If other methods can be used to ensure the headstock gear span, this item can be omitted.
- 8) The relative difference of the two support leg's height, taken as the distance from the wheel's working surface to the support leg's upper flange surface, shall be no greater than 8 mm.

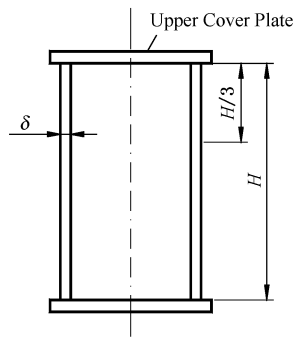


Figure 6 Schematic diagram for wave degrees of main beam main web for the movable headstock gear

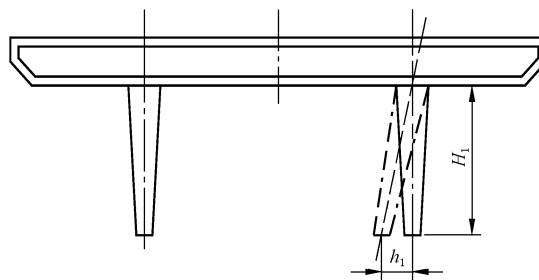


Figure 7 Schematic diagram for perpendicularity of outriggers in the spanning direction for the movable headstock gear

b) Track installation of a small cart/crab (or mobile trolley) shall meet the following requirements:

- 1) The deviation of the crab track gauge (Fig 2) shall be no greater than  $\pm 3$  mm.
- 2) The relative difference of the crab span  $T_1, T_2$  (Fig 3) shall be less than 3 mm.
- 3) The relative difference of the crab track elevation (Fig 8) in the same cross section shall be less than 3 mm.
- 4) The position deviation between the crab track centre line and the track beam web centre line (Fig 9) shall be less than  $0.5\delta$ , where  $\delta$  is the track beam webplate's thickness.
- 5) The crab track's local bending in the lateral direction shall be no greater than 1 mm in any 2 m segment length.
- 6) The crab track shall connect closely with the girder's upper flange plate. If the local gap is wider than 0.5 mm and longer than 200 mm, a sub-plate shall be added into the gap.
- 7) The crab track joint's height difference and lateral misalignment shall both be less than 1 mm and the gap between joints shall be less than 2 mm.

c) Large cart track installation shall meet the following requirements:

- 1) The carts wheels shall be connected with the track's surface and shall not be suspended.

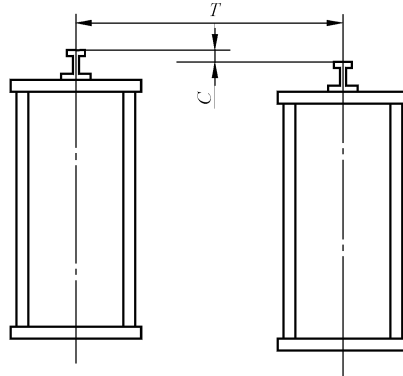


Figure 8 Schematic diagram for trolley track elevation difference on the same section for the movable headstock gear

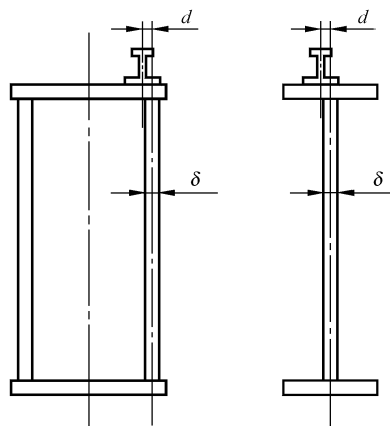


Figure 9 Schematic diagram for positional deviation between centre line of the trolley track and that of the track beam web for the movable headstock gear

- 2) Before laying the steel tracks, the quality certifications of the steel tracks shall be checked. Only when they have passed inspection can the tracks be laid.
- 3) Before hoisting the tracks, the track installation datum line shall be determined and the deviation between the actual track centre line and datum line shall be less than 2 mm.
- 4) The track gauge deviation shall be no greater than  $\pm 5$  mm.
- 5) The track's lateral local bending shall not be greater than 1 mm in any 2 m segment length.
- 6) The difference between the highest and lowest points of each track over the entire stroke shall be less than 2 mm.

- 7) The relative difference in track elevation at the same cross section shall be less than 5 mm.
  - 8) Joint positions of two parallel tracks shall be staggered and the staggered distance shall be greater than the wheelbase between the front and back wheels. The height difference and lateral misalignment of the joints shall be less than 1 mm and the gap between joints shall be less than 2 mm.
  - 9) For ground wire connection with the track, a ground resistance test shall be done, and the ground resistance shall be less than 4  $\Omega$ .
- d) The travelling mechanism installation shall meet the following requirements:
- 1) The span deviation shall be no greater than  $\pm 5$  mm and the span's relative difference shall be less than 5 mm.
  - 2) The wheel's vertical deflection shall be measured when the wheel is overhead and the vertical deflection shall be less than  $L/400$  mm ( $L$  is the measuring length).
  - 3) The wheel's horizontal deflection shall be less than  $L/1\ 000$  ( $L$  is the measuring length). The deflection on the same wheel axial line shall be in opposite directions.
  - 4) Differential position of wheels in the same end beam: if there are two wheels, it shall be less than 2 mm; if there are more than two wheels, it shall be less than 3 mm. The differential position of wheels in the same balance beam shall be no greater than 1 mm.

**8.3.6** Screw-type headstock gear installation shall meet the following requirements:

- a) After arrival at the site, the headstock gear shall be unpacked and checked. Only when the headstock gear has passed the acceptance can it be installed.
- b) After cleaning the headstock gearbox, new lubricant oil shall be added to meet the oil level requirements. The oil seal and interface shall have no oil leakage.
- c) Check the embedding position of the foundation bolts to ensure the bolt's extension length shall meet the installation requirements.
- d) The headstock gear platform's elevation deviation shall be no greater than  $\pm 5$  mm and its horizontal deviation shall be no greater than  $0.5/1\ 000$ .
- e) The distance deviation between the headstock gear base's lengthwise or crosswise centre line and the centre line of the sluice gate's hoisting eye shall be no greater than  $\pm 1$  mm.
- f) The local gap between the headstock gear base and the foundation plate shall be no greater than

0.2 mm and the non-contacting surface area shall be no greater than 20% of the total contact surface area.

**8.3.7** Trial operation of fixed winch type headstock gear shall meet the following requirements:

- a) Trial operation testing is to be carried out on site, while the test records and quality inspection shall be finished as well. A trial operation test may be conducted in coordination with the equipment installation and commissioning.
- b) The requirements for electrical equipment are as follows: Before the power connection test, all the wiring shall be carefully checked to meet the drawing requirements. Only when the entire circuit's insulation resistance is greater than 0.5 MΩ can the power connection testing be done. During the test, the temperature rise of each electric motor and electrical component cannot be greater than its allowable value. The headstock gear's own electrical equipment shall be used to do the test. If any component such as a contact terminal is burnt out during the test, it shall be replaced.
- c) Zero load tests. The headstock gear shall be operated back and forth 3 times along the entire stroke during the zero load testing. Check and adjust the following electrical and mechanical parts:
  - 1) The electric motor shall run steadily and the degree of unbalance of the three-phase current shall be no greater than  $\pm 10\%$ . The electrical equipment shall not reveal abnormal heating.
  - 2) When the headstock gear runs to the limit position of the stroke, the control switch can send signals and automatically cut off the power to stop running.
  - 3) When all the mechanical parts are running, there shall be no impact sound or other abnormal sounds. The steel wire rope shall not rub other parts in any position.
- d) Load tests.
  - 1) The operation testing of the hoist and gate should be carried out under the design head conditions and the gate shall be closed twice under dynamic water conditions.
  - 2) Transmission parts run smoothly without any abnormal sound, heating, or oil leakage.
  - 3) The action of travel switch shall be sensitive and reliable.
  - 4) For screw hoist equipped with load control device and height indicator, special tests shall be carried out on the transmission and reception of sensor signals to ensure that the action is sensitive, and the instructions are correct, safe and reliable.

- 5) Synchronous lifting of hoists with double lifting eyes shall not be stuck.
- 6) Motor-driven operations shall be stable, and the transmission belt shall not slip.

**8.3.8** The trial operation of hydraulic headstock gear shall meet the following requirements:

- a) Before the trial operation of the hydraulic cylinder, all obstacles in the working area shall be cleared away to ensure that the sluice gate and hydraulic cylinder can run without blockage.
- b) The oil filtering core shall be cleaned and replaced if necessary to ensure the hydraulic system's degree of pollution is no less than Level NAS9.
- c) The environmental temperature shall be no lower than the lowest design temperature.
- d) If the rack is attached by welding, the welding joints shall be checked to meet relevant requirements. If the rack is attached by anchor bolts, the screw nuts shall be checked to prevent loosening.
- e) Each component shall be debugged in the electrical circuit to ensure it meets the relevant requirements.
- f) When the oil pump starts for the first time, open the flood valve completely and keep it idling for 30 min. The oil pump shall have no abnormal phenomenon.
- g) If the oil pump idling is normal, the flood valve shall be gradually screwed tight to fill the pipeline system with oil. Air shall be exhausted in the process of filling oil. When the pipeline is full of oil, the oil pump's flood valve shall be adjusted to make sure that the oil pump system has no vibration, noise and overheating when it keeps running respectively under 50% , 75% and 100% of working pressure for 5 min. Check the valves and pipelines to see if there is any oil leakage.
- h) Adjust the oil pump's flood valve to ensure that it can extract oil automatically when its pressure reaches 1.1 times its working pressure. The pump shall have no severe vibration and noise at this time.
- i) Open and close the sluice gates. Check the speed reducing function of the hydraulic cylinder's buffer device. Check if the sluice gate has any blockage. Record the running water head's and the sluice gate's system pressure in the opening process.
- j) Only when the manual operation test has been correctly performed can the automatic operation test be done.
- k) When doing the sluice gate's rapid closing test, some values shall be properly recorded such as the gate's hoisting force, rapid closing, holding force, buffering time, reservoir water level and

system pressure at that time. The rapid closing time shall meet the design requirements. When doing rapid closing tests, emergency measures of cutting off the oil circuit shall be implemented to prevent the sluice gate from opening or closing at too high a speed.

- l) The hydraulic headstock gear shall be used to hoist the sluice gate. A slippage test is then carried out and shall meet the following requirements; the amount of slippage of the sluice gate  $p$  due to the hydraulic cylinder's internal oil leakage shall be no greater than 100 mm over 24 hrs. When the sluice gate slippage is greater than 100 mm after 24 hrs, alarm signals shall be generated. When the sluice gate slippage is greater than 200 mm, the hydraulic system shall be able to be reset automatically. The system shall not automatically reset more than twice in 72 hrs.
- m) For a single hydraulic headstock gear which has double lifting points and an automatic rectifying function, if the deviation from synchronous travel between its two hydraulic cylinders exceeds the design value in any position of the stroke, it shall be corrected by the automatic rectifying devices.

**8.3.9** The trial operation of mobile headstock gear shall meet the following requirements:

- a) Before trial operation, the following items shall be checked:
  - 1) Check the installation of all mechanical parts, connecting parts, protection devices and the oil filling condition of the lubricating system. The result of the check shall meet relevant requirements and all the sundry items on both sides of the track shall be removed.
  - 2) Check the steel wire rope to ensure the ends are firmly attached and make sure the rope has been wound in the right direction on the coiling block or the pulley wheel.
  - 3) Check the cable's coiling block, central electrical conducting device, slide wire, transformer and each motor to see whether the wiring is correct and whether or not the wiring is loose. The ground connection shall be checked as well.
  - 4) For a hoisting mechanism with dual motor drives, the electric motor shall be checked to see if the running direction is correct and if the rotational speeds of the two drives are synchronous. For a hoisting mechanism with dual hoisting points, the steel wire ropes on both sides shall be adjusted to be of equal length.
  - 5) Check the running mechanism to see whether the electric motor's running direction is correct and whether the rotational speeds are synchronous.
  - 6) Turn each mechanism's brake wheel by hand to make sure the last axle (such as the wheel axle and coiling block axle) has no blockage when completing a single turn.
- b) Trial operation shall meet the following requirements:

- 1) The hoisting mechanism and running mechanism shall be operated back and forth along the entire stroke 3 times. The degree of unbalance of the electric motor's three-phase current shall be no greater than 10%. The electrical equipment shall have no abnormal heating phenomenon and the controller's contact terminals shall not be burnt.
  - 2) Limit switches, protection devices and interlock devices shall move correctly and reliably.
  - 3) When the cart and the crab are running, the wheels shall not bite the rail.
  - 4) When the cart and the crab are running, the electrical conducting devices shall work steadily and have no blockage, jumping or serious sparks.
  - 5) When all the mechanical parts are running, they shall have no impacting or other abnormal sounds.
  - 6) During the running process, the brake shoe shall be completely separate from the brake wheel and shall not rub against the wheel.
  - 7) All the bearings and gears shall be well-lubricated and the bearing temperature shall be no higher than 65 °C.
  - 8) The noise measured without disturbance at the driver's seat (when the window is closed) shall be no greater than 85 dB (A).
  - 9) For headstock gear with a hooking beam, sluice gate hooking tests shall be done.
  - 10) For headstock gear with dual lifting points, tests shall be done to inspect the horizontal deviation of the sluice gate's hoisting eye centre line. Synchronous testing of the double lifting points shall be also done.
- c) Dead load tests shall meet the following requirements:
- 1) Check the bearing capacity of each part of the headstock gear and the hydro-mechanical structures.
  - 2) Measure the girder's actual camber and the cantilever's actual degree of lifting.
  - 3) Determine the weakest section of the girder and rack and set stress test points.
  - 4) The installation site shall have weight blocks as required by dead load tests. Special dedicated blocks should be used.
  - 5) Increase the load gradually from 75% to 125% of rated load during the test. Keep the gate



100 mm to 200 mm above the ground for no less than 10 min and measure the gantry or bridge frame deflection. Then unload and measure the distortion of the gantry or bridge frame.

- 6) During the dead load test, the measured girder deflection shall be less than  $L/700$  and the cantilever's measured deflection shall be less than  $L_n/350$ .
  - 7) After the dead load test, each component and each part of the hydro-mechanical structure shall have no quality problem which would affect the component's properties and safety such as fractures, permanent distortion, loose connections or damage.
- d) Dynamic load tests shall meet the following requirements:
- 1) Check the working properties of the mechanism and brake.
  - 2) Increase the load gradually from 75% to 110% of rated load and keep repeating the operations such as lifting up, lowering down, pause and then lift and lower again for 1 hr.
  - 3) When using the headstock gear as the crane, not only shall the lifting up, lowering down and pause tests be done under 1.1 times rated lifting load according to the crane's operating condition and rated lifting weight, but also walking tests shall be also done for the cart and crab.
  - 4) Check each mechanism carefully during the dynamic load test. They shall be able to move freely and work steadily and reliably. Each limit switch and safety protection interlock device shall move correctly and reliably. No joint shall be loose.

8.3.10 The lifting load testing of the bridge crane shall meet the following requirements:

- a) Lifting load testing shall include the following contents:
  - Static load test;
  - Dynamic load test;
  - Stability test (when required).
- b) Static load testing shall meet the following requirements:
  - 1) The purpose of static load testing is to test the carrying capacity of the cranes and their structural parts. If no cracks, permanent distortion, paint peeling or damage to the performance and safety of the crane are observed and the joints do not become loose or damaged, the test results are considered to be qualified.

- 2) The static load test of each hoisting mechanism shall be carried out separately. If the crane's specification so allows, the static load testing of the combined action of the hoisting mechanism shall also be carried out. The crane shall be in the position and condition where the main parts bear the maximum load, the maximum bending moment and/or the maximum axial force according to the actual use. The test load shall be gradually added up and raised to a distance of 100 mm to 200 mm from the ground, and the suspension time shall not be less than 10 min. The higher value shall be in accordance with national regulations or the contract.

When a static load test makes it impossible for each main component of the crane to withstand the maximum bending moment and/or the maximum axial force, additional static load tests or tests to withstand the required forces shall be carried out.

- 3) If there is no higher value requirement in national regulations or order contracts, the test load of all cranes shall be  $1.25P$ , where  $P$  is defined as:

For mobile cranes, the rated lifting weight (the load mass on the lifting mechanism, including the effective lifting weight and the mass of the hook pulley set);

For other types of cranes, the maximum lifting weight specified by the manufacturer.

- c) The dynamic load test shall meet the following requirements:

- 1) The main purpose of dynamic load testing is to verify the functions of the crane mechanism and brake.
- 2) In addition to the lifting mechanism, each mechanism of the crane shall carry out  $1.25P$  bearing testing at the low speed specified by the manufacturer.

Each mechanism of the crane shall carry out  $1.1P$  dynamic load testing separately. If specified in the crane specifications, the joint action test shall be carried out. The test shall be carried out in the position and state of each mechanism bearing the maximum load. The test shall include repeated the starting and braking of each mechanism throughout its entire range of motion, as well as air starting of suspended test load, at which time the test load shall not move uncontrollably.

- 3) If the functional test of each component can be completed and no damage to the mechanism or structural component is found in the subsequent visual inspection, and the connection is not loosened or damaged, the test result is considered to be qualified.
- 4) In dynamic load testing, the crane shall be controlled according to the operating manual, and the acceleration, deceleration and speed shall be limited to the normal working range of the crane.

d) Stability test

- 1) The purpose of stability testing is to test the crane's ability to resist the overturning moment. When the test load is applied on the crane hook without impact, the crane can maintain stability, and the test results are considered to be qualified.
- 2) The stability test shall be carried out in the most unfavourable position or status in the specified working area. If the loads specified in different locations or working areas are different, the stability tests for these conditions shall be carried out selectively.
- 3) The test load shall be added gradually, rising to 100 mm to 200 mm from the ground, and the hanging time shall not be less than 5 min. The higher value shall be specified by national regulations or the order contract.
- 4) For cranes other than mobile cranes, the test load shall be  $1.25p$ , the higher value shall be specified by national regulations or the order contract, where  $P$  shall be stipulated by the manufacturer.

e) Test conditions

- 1) In order to carry out the test, cranes shall install working devices suitable for operation according to the specifications.
- 2) For cranes operating on rails, tests shall be carried out on rails manufactured and laid in accordance with crane specifications.
- 3) For cranes other than cranes operating on rails, tests shall be carried out in accordance with national regulations or order contracts.
- 4) The wind speed shall be no greater than 8.3 m/s (30 km/hr) during the test. Except as stipulated in the order contract, the crane is not required to be in the most unfavourable wind direction.

**8.3.11** The trial operation of screw-type headstock gear shall meet the following requirements:

- a) Trial operation shall be done at the work site. Test recording and quality checks shall be properly done. Test running can be combined with equipment debugging.
- b) Electrical equipment tests shall meet the following requirements:
  - 1) Before the power connection test, all the wiring shall be checked in order to meet the drawing requirements.

- 2) The circuit's insulation resistance shall be greater than 0.5 MΩ.
  - 3) During the test, each electric motor and electrical component's temperature rise cannot be greater than the allowable value.
  - 4) The headstock gear's own electrical equipment shall be adopted during the test.
  - 5) Component contact terminals which get burnt shall be replaced.
- c) Zero load tests shall meet the following requirements:
- 1) Headstock gear running tests without the sluice gate shall be done back and forth 3 times over the entire stroke.
  - 2) When the electric motor is running, the degree of unbalance in the three-phase current shall be no greater than  $\pm 10\%$  and the electrical equipment shall have no abnormal heating phenomenon.
  - 3) When the headstock gear runs to the upper and lower limit position of the stroke, the limit switch shall be able to send signals and automatically cut off the power to stop the headstock gear from running.
  - 4) When all the mechanical parts are running, there shall be no impacting or other abnormal sounds.
- d) Loads tests shall meet the following requirements:
- 1) The headstock gear's running test with the sluice gate should be done at the design water head. The sluice gate shall be closed twice in flowing water conditions.
  - 2) The transmission parts shall run steadily and have no abnormal sound, heating or oil leakage.
  - 3) The stroke switch shall move sensitively and reliably.
  - 4) For screw headstock gear with load control and height indicating devices, special tests shall be done to check the sending and receiving of the sensor's signal in order to ensure the mechanism can move sensitively and give indications correctly, safely and reliably.
  - 5) For headstock gear with dual lifting points, synchronous lifting up and down shall have no blockages.
  - 6) The operation of the electric motor shall be steady and the transmission belt shall have no

slippage phenomenon.

#### 8.4 Installation of penstocks

##### 8.4.1 Installation of penstocks shall meet the following requirements:

- a) Pipe centre, elevation, mileage, and other control points should be permanently retained and clearly marked before penstocks are installed.
- b) Semi-mechanized thermal cutting should be used to cut the margin of the joint of penstocks installed on site, and the cutting quality and dimensional deviation shall meet the relevant provisions. The oxide layer, molten slag, and burrs on the cutting surface shall be grinded using the grinding wheel. The depth of groove caused by the cutting should not exceed 0.5 mm. Otherwise, the groove shall be grinded. If the groove depth is greater than 2 mm, the groove shall be welded and grinded to meet mandated requirements. The penetration test shall be conducted within a 20 mm scope of the welded area and the surrounding area. The acceptance grade for defect display is 2.
- c) The strength, stiffness, and stability of the penstock supports shall be calculated by design, and no overturning or collapse shall occur.
- d) The high-altitude operation platform for penstock fabrication and installation shall meet the following requirements:
  - 1) The operation platform, wire rope, and locking device shall be determined through design calculation.
  - 2) There shall be safety protection devices.
  - 3) Steel wire ropes are strictly prohibited from passing through sharp parts.
  - 4) Electrical devices, such as welding machines, shall be insulated from electricity and grounded reliably. Operating platforms shall not be used as grounding circuits.
  - 5) Reliable fire and fall prevention measures shall be taken.
- e) Penstocks piers shall be of sufficient strength and stability, and no displacement or distortion shall occur during the installation of penstocks.
- f) It is not suitable to weld any other temporary components, such as support or footplate, freely on the penstock wall.

##### 8.4.2 Installation of the embedded penstock shall meet the following requirements:

- a) The allowable installation error of the embedded penstock's centre shall meet the requirements of Table 55.
- b) The starting segment's deviation along its length shall be no greater than  $\pm 5$  mm. The length deviation of the elbow's starting point shall be no greater than  $\pm 10$  mm. The degree of vertical deviation of the starting segment's pipe orifice shall be no greater than  $\pm 3$  mm.

**Table 55 Allowable error of embedded penstock's installation centre** Unit: mm

Penstock inner diameter $D$	Allowable error of the orifice centre of the starting segment	Orifice centre's allowable error of pipe segments and the starting points of elbows which are connected with volutes, expansion joints, butterfly valves, ball valves and bifurcated pipes	Orifice centre's allowable error of pipes in other parts
$D \leq 2\,000$	5	6	15
$2\,000 < D \leq 5\,000$		10	20
$D > 5\,000$		12	25

- c) Shape deviation of the penstock cross-section shall meet the following requirements:
  - 1) For penstocks with circular cross-sections, the roundness shall not be greater than  $5D/1\,000$  nor greater than 40 mm (two pairs of diameters shall be measured at each end).
  - 2) For penstocks with non-circular cross-sections, the dimensional deviation shall be no greater than 5% of the design dimension, and the absolute value shall be no greater than 8 mm.
- d) The flatness of the penstock orifice shall be no greater than 6 mm.
- e) Unless required by the drawings, the circular seams shall be welded one by one and not out of order or assembled by force. Components such as temporary supports or pedal plates shall not be welded to the pipe wall at will. The circular seams shall not be re-welded after casting of the concrete.
- f) When the penstock's fixtures, hoisting eyes, inner supports and other temporary components are dismantled, carbon arc-air gouging or an oxygen-acetylene flame shall be used instead of hammering to cut these components at a position at least 3 mm from the pipe wall, and the parent metal shall not be damaged. After dismantling, the residual traces and welding scars on the penstock's inner wall shall be sanded down by grinding wheels. The pipe wall shall be properly checked to see if there are any tiny fissures.
- g) After the installation, the penstock shall be welded together with the buttress and anchor bolts to prevent displacement caused by concrete casting.
- h) For the pipe's outer and inner walls, any localised pits whose depth is no greater than 10% of

the wall thickness and is no greater than 2 mm, may be polished using grinding wheels to smooth the surface. For pits whose depth is greater than 2 mm, carbon arc-air gouging or grinding wheels shall be used to gouge or rub the pits to become grooves which are easy to repair by welding.

- i) The follow-up construction of threaded holes of grouting holes shall not continue until the hollow threaded jacket is installed.
- j) When the plug of a grouting hole is welded through melting, the groove depth of the plug should be 7 mm to 8 mm. If the plugs of grouting holes are to be blocked by adhesion or using other methods, it shall be fully demonstrated and tested.
- k) Penstocks shall be welded with buttress and anchor bolts after being installed. After elastic cushion pipes are installed, the outer support shall be removed and the pipes polished.
- l) The buried pipe should be supported by movable internal support. When a fixed support is used, the connection between the fixed support and the penstock should be welded by the transition plate with the same material as the penstock.

**8.4.3** Installation of exposed penstocks shall meet the following requirements:

- a) The top surface camber of saddle-type supports shall be checked by regular templates and the gap between the surface and the template shall be no larger than 2 mm.
- b) For roller type and swing type buttresses, the sub-plate elevation and lengthwise and crosswise centre deviations shall be no greater than  $\pm 5$  mm. The parallel deviation between the penstock's actual and design axis shall be no greater than 2/1 000. If the drawing has special requirements, the sub-plate elevation deviation shall comply with them.
- c) After installation, the roller type and swing type support shall be able to move freely without blockage. Each contact surface shall be properly connected and the local gap shall be no wider than 0.5 mm.
- d) The allowable deviation of the exposed pipe installation centre shall conform to the provisions of Table 55. After exposed pipes are installed, the roundness and shape deviation of the pipe orifice shall conform to the provisions of 8.4.2.
- e) Removal of internal supports, fixtures, lugs and other temporary components of penstocks, and treatment and welding of pits on the inner and outer surfaces of penstocks shall be consistent with the provisions of 8.4.2.
- f) During expansion joint installation, the influence of ambient temperature shall be considered for adjustment of expansion and contraction. Calculation of penstock expansion and retraction affected by the ambient temperature shall conform to the regulations.

- g) Installation of expansion joints of corrugated pipes shall meet product technical requirements.
- h) When the expansion joints of corrugated pipes are welded, the ground electrodes of the welding machine cannot be welded onto the corrugated body.
- i) When the last closure weld between two piers is welded, the expansion joint shall be relieved.

**8.4.4** Welding of penstocks shall be performed in accordance with the following requirements:

- a) All welded joints shall be inspected for appearance, and appearance quality shall be consistent with the requirements in Table 56.

**Table 56** Appearance inspection of welded joints

Unit: mm

No.	Item		Weld Joint type		
			I	II	III
			Allowable defect dimension		
1	Crack		Not allowed		
2	Surface inclusion		Not allowed	Depth: no greater than $0.1\delta$ Length: no greater than $0.3\delta$ and 10	
3	Undercut		Depth: no greater than 0.5	Depth: shall not be greater than 1	
4	Incompletely filled weld		Not allowed	It shall not be greater than $0.2 + 0.02\delta$ nor shall it exceed 1, and the total length of every 100 weld defects shall not exceed 25.	
5	Surface blowhole		Not allowed	For blowhole with a diameter smaller than 1.5, 5 blowholes are allowed within each meter, and the spacing shall not be less than 20.	
6	Weld beading		Not allowed	—	
7	Spatter		Not allowed	—	
8	Surplus height of seam $\Delta h$	Manual welding	$\delta \leq 25 \quad \Delta h = 0 \sim 2.5$ $25 < \delta \leq 50 \quad \Delta h = 0 \sim 3$ $\delta > 50 \quad \Delta h = 0 \sim 4$	—	
		Automatic welding	0~4	—	
9	Butt joint weld width	Manual welding	Groove width of 1—2.5 at each side is covered and smoothly transitioned.		
		Automatic welding	Groove width of 2—7 at each side is covered and smoothly transitioned.		
10	Leg of a fillet weld ( $K$ )		$K \leq 12, K^{+2}; K > 12, K^{+3}$		
<p><b>NOTE 1</b> <math>\delta</math> is a document for steel plate thickness.</p> <p><b>NOTE 2</b> Manual welding refers to shielded metal arc welding, CO<sub>2</sub> semi-automatic gas shielded welding, self-shielded flux core semi-automatic welding, and manual TIG welding. Automatic welding refers to union melt welding, MAG automatic welding, MIG automatic welding, and self-protecting flux core automatic welding.</p>					



- b) Ultrasonic testing(UT)or radiographic testing (RT) is used for internal quality testing of welded joints; magnetic particle testing (MT) or penetration testing (PT) is used for surface quality testing of welded joints; magnetic particle testing (MT) is preferred for ferromagnetic materials. When problems are detected using one of non-destructive testing methods, another non-destructive testing method shall be used for re-examination. Ultrasonic testing includes pulse reflection ultrasonic testing (UT), phased array ultrasonic testing (PA-UT), and time of flight diffraction (TOFD).
- c) Phased array ultrasonic testing (PA-UT) can be used for T-shaped joints or for narrow space.
- d) The percentage of non-destructive testing length of the welded joint compared to the entire weld joint length shall not be less than that specified in Table 57.

**Table 57 Percentage of NDT length compared to entire weld joint length**

No.	Steel type	Pulse reflection ultrasonic testing (UT) or phased array ultrasonic testing (PA-UT) (%)		Time of flight diffraction (TOFD) or radiographic testing (RT) (%)	
		Class I weld	Class II weld	Class I weld	Class II weld
1	Low carbon steel and low alloy steel	100	50	25	10
2	High-strength steel, stainless steel and stainless steel compound plate	100	100	40	20

**NOTE 1** It is preferable to select a T-butt weld and other parts, which are prone to have weld defects, for casual inspection. At least 2 spots shall be inspected for each weld and the spacing between adjacent inspection spots shall not be less than 300 mm.

**NOTE 2** The length of TOFD or RT inspection shall not be less than 150 mm. UT or PA-UT shall be selected for the parts with more defects or where it is required to further determine the property of defects.

**NOTE 3** When it is sceptical to use the UT or PA-UT method, the TOFD or RT method can be used for re-examination.

- e) NDT shall meet the following requirements:
  - 1) RT shall be carried out in accordance with the relevant provisions. The technical level of RT shall be Grade B. The first class welds shall be qualified if they are no lower than Grade I, and the second class welds shall be qualified if they are no lower than Grade II.
  - 2) UT and PA-UT shall be carried out in accordance with the relevant provisions. The technical level of RT shall be Grade B. The first class welds shall be qualified if they are Grade I, and the second class welds shall be qualified if they are no lower than Grade II.
  - 3) TOFD shall be carried out in accordance with relevant provisions or the industry standards currently in effect; the first class welds and second class welds are qualified if they are no lower than Grade II.

- 4) MT shall be carried out in accordance with relevant regulations. The first class welds with Grade II are qualified and the second class welds with Grade III are qualified.
- 5) When two or more NDT methods are used to detect the same welded joint or the same welded defect, qualification shall be assessed according to their respective standards.
- f) In partial non-destructive testing of welded joints, when a disallowed defect is detected, NDT shall be carried out again in the extension direction of the defect or in the suspicious part, and length of supplementary testing shall not be less than 250 mm. When the disallowed defect is still detected after the supplementary NDT is conducted, welded joints operated by the welder shall be checked or 100% NDT shall be conducted for all welded joints.
- g) Welded joints being reprocessed for defects shall be re-inspected according to the original NDT process, and the scope of the re-inspection shall be extended at least 50 mm to both ends of the reprocessed area.

**8.4.5** Anti-corrosion of penstocks shall be consistent with the following specifications:

- a) Surface pre-treatment shall meet the following requirements:
  - 1) Rust, oil stains, water accumulation, missing welding slags and splash shall be removed before penstock surface pre-treatment.
  - 2) Rust shall be removed through local spraying or blasting for surface pre-treatment. The abrasive to be used shall be clean and dry. Metal abrasive, alumina, garnet, copper slag, silicon carbide, and emery are used. The particle size of metal abrasive should be in the range of 0.5 mm to 1.5 mm. Artificial mineral abrasive and natural mineral abrasive shall be selected according to technical requirements for surface roughness, and the particle size should be in the range of 0.5 mm to 3.0 mm. Steel abrasives are not allowed in a wet environment.
  - 3) Oil and water shall be filtered and removed from the compressed air used for local spraying.
  - 4) Surface cleanliness of the penstock inner wall shall conform to PSa2.5 grade after the rust on the inner wall is removed through partial injection or blasting. After rust removal, the surface roughness of thick-paste heavy-duty coatings and metal thermal spraying shall reach Rz60  $\mu\text{m}$  to Rz100  $\mu\text{m}$ , and the surface roughness of other materials shall reach Rz40  $\mu\text{m}$  to Rz70  $\mu\text{m}$ . Surface roughness is measured using a contact-pin contour graph or visually evaluated by comparing it with sample plates.
  - 5) Surface cleanliness of the penstock outer wall shall conform to specifications in Table 58 when cement slurry or coating is used for corrosion protection after the rust on the outer wall is removed through partial injection or blasting.

Table 58 Quality requirements for pre-treatment of penstock outer wall surface

No.	Position	Coating system	Surface clearness	Surface roughness Rz ( $\mu\text{m}$ )
1	Exposed pipe outer wall	Spray coating	PSa2.5	40, 70
2	Buried pipe outer wall	Modified cement mortar or caustic soda cement slurry	PSa2	—

- 6) After penstock rust is removed, dry compressed air or a vacuum cleaner shall be used to remove dust. When the steel plate surface is contaminated or rusted before painting, the steel plate shall be re-treated to the original rust removal grade.
  - 7) When the relative humidity of the air is greater than 85%, the ambient temperature is lower than 5 °C, and the surface temperature of the steel plate is 3 °C lower than the dew point in the atmosphere, rust removal shall not be carried out.
- b) Coating shall meet the following requirements:
- 1) The coating system for anti-corrosive coating should be composed of primer, intermediate coat, and finishing coat. Primers shall have good adhesion and anti-corrosion performance. Intermediate coats shall have shielding properties and can be properly combined with primers and finishing coats. Finishing coats shall be abrasion-resistant, weather-resistant, or water-resistant.
  - 2) The selection of coating matching system shall be based on the environment as follows:
    - The coating for outer walls of buried pipe is usually modified cement slurry or caustic soda slurry. When the outer wall of the exposed pipe is in the air environment, the coating system with good weather resistance properties shall be selected.
    - The inner wall of the steel tube shall have a coating matching system applied with good wear-resistance and water-resistance.
    - In addition to wear-resistance and water-resistance, the coating for the inner wall of the water conveyance pipeline shall meet the requirements of the sanitary standards.
  - 3) The steel surface with rust removed should have a coating applied on the surface within 4 hrs. It shall be coated within 12 hrs at most under sunny and normal atmospheric conditions.
  - 4) Coatings to be used shall conform to the drawings. The number of coating layers, the thickness of each coating, time interval between coatings, formulation of the coating and notes

for coatings shall be consistent with design documents or relevant regulations.

- 5) Penstock joints shall be coated with workshop primers, such as inorganic zinc-rich primers, within the scope of 200 mm on both sides of the ring seam and 100 mm around the grouting and drainage holes. After installation and welding, surface pre-treatment and coating are carried out according to the regulations.
  - 6) When the relative humidity of the air is greater than 85% and the surface temperature of the steel plate is 3 °C lower than the dew point of the atmosphere or higher than 60 °C, or the ambient temperature is lower than 10 °C, coating shall not be carried out.
- c) Coating quality inspection shall meet the following requirements:
- 1) Before each coating, the appearance of the previous coating shall be inspected. Defects, such as leakage, sagging, and wrinkles, shall be promptly dealt with. The wet film thickness shall be measured using a wet film thickness gauge after coating.
  - 2) The appearance shall be inspected after coating. Coating surface shall be smooth, uniform in colour, without wrinkles, bubbles, sagging, pinholes, cracks, missing coating and other defects. The thickness of the cement slurry coating shall be basically the same, with strong adhesion and without powder.
  - 3) Coating internal quality shall meet the following requirements:
    - Coating thickness is measured using a coating thickness gauge. Three measurements are to be made on the 0.01 m<sup>2</sup> base level. Distance between measurement positions shall be 25 mm to 75 mm. The arithmetic average value of three measurement values shall be taken as the thickness of one measuring point on the base level. For coatings with surface roughness greater than Rz100 µm before coating, the arithmetic average value of 5 measurement values shall be taken as the thickness of measuring points.
    - When the inner surface area of a single penstock is greater than or equal to 10 m<sup>2</sup>, there shall be no less than 3 measuring points on every 10 m<sup>2</sup> surface; when the inner surface area of a single penstock is less than 10 m<sup>2</sup>, there shall be at least one measuring point on every 2 m<sup>2</sup> surface. A measuring point is set every 1.5 m on the circumference of the single penstock between the two ends and in the middle. For thickness of coating, the thickness at 85% of the measuring points shall meet design requirements. For the measuring points where the thickness does not meet design requirements, the minimum thickness shall not be less than 85% of the design thickness.
    - A pinhole detector for coatings without conductive elements is mainly used for inspecting the coating on both sides of the annular seam. The pinholes shall be detected according to the voltage value in Table 59. Detected pinholes shall be polished using abra-

sive paper and flexible grinding disc and then coated again.

**Table 59 Relationship between coating thickness and detection voltage**

Coating thickness ( $\mu\text{m}$ )	100	150	200	250	300	350	400	500	600	800	1 000
Voltage (kV)	$\geq 1.0$	$\geq 1.2$	$\geq 1.5$	$\geq 1.7$	$\geq 2.0$	$\geq 2.2$	$\geq 2.4$	$\geq 2.9$	$\geq 3.3$	$\geq 4.0$	$\geq 4.7$

- 4) The coating thickness is insufficient or there are pinholes. After reworking, it shall be rechecked.
- 5) Cutting method is adopted to inspect adhesive force:
  - When coating thickness is greater than 120  $\mu\text{m}$ , scratch two intersection lines with an included angle of  $60^\circ$  using an inserted tool. The cutting of intersection lines shall penetrate the coating to the base materials. Scratch sections shall be secured with adhesive tapes. Then the adhesive tapes are quickly torn off along the vertical direction. The coating is qualified without peeling off.
  - When the coating thickness is less than or equal to 120  $\mu\text{m}$ , two bunches of parallel lines perpendicular to each other are scratched on the surface at a distance of 3 mm to 5 mm using a special tool, forming several grids. The adhesive force of the coating shall be checked according to the requirements in Table 60, and coating with Grades of 0 to 2 is qualified.

**Table 60 Adhesive force test using cutting method**

Grade	Detection result
0	The cut edge is completely smooth without a square falling off.
1	A few thin sheets are separated from the cutting cross-section. The grid area is affected less than 5%.
2	Coating exfoliated along the cut edge or incision intersection is obviously greater than 5% , but the impact is no more than 15%.
3	Along the cut edge, the coating partially and entirely peels off with large fragments, or in different parts of grids. The peeling off area is greater than 15% and affected grids are no greater than 35%.
4	Coating peels off with large fragments along the cut edge or partially and entirely in grids. The peeling off area is greater than 35% and the affected grids are no greater than 65%.
5	The peeling off degree cannot be identified by Grade 4.

- 6) When quantitative detection of the adhesive force is conducted using the pull-out method (pull-off method), adhesive force indexes can be negotiated by the supplier and the user according to Table 61. The pull-off coating adhesion tester can be used for the pull-out method. The testing can be carried out according to specifications for the instrument.

Table 61 Adhesive force test using pull-off method

Unit: N/mm<sup>2</sup>

Coating type	Adhesive force
Epoxy, polyurethane, fluorocarbon coatings	≥5.0
Chlorinated rubber, acrylic resin, ethylene resin, inorganic zinc-rich, epoxy asphalt, and alkyd resin	≥3.0
Phenolic resin and oil-based coatings	≥1.5

- 7) The adhesive force test can be conducted using the cutting method or the pull-off method. Any of the methods is acceptable.

d) Metal spraying shall meet the following requirements:

1) Metal wires used for metal spraying shall meet the following requirements:

- Zinc wires shall meet quality requirements and Zn≥99.99%.
- Aluminium wires shall meet quality requirements and Al≥99.5%.
- Aluminium content in Zn-Al alloy wires shall be 13% to 35% , and the rest is zinc.
- Magnesium content in AL-Mg alloy wires shall be 4.8% to 5.5% , and the rest is aluminium.
- Wires shall be clean, rust-free, oil-free and crease-free, with a diameter of  $\phi 3.0$  mm.

2) Electric arc spraying should be used. Flame spraying can be applied to parts where arc spraying cannot be carried out.

3) Metal spraying can be carried out by thickness below according to different spraying materials and the working environment:

- Thickness of zinc or aluminium sprayed layer should be 120  $\mu\text{m}$  to 150  $\mu\text{m}$ .
- The zinc aluminium alloy layer, the aluminium magnesium alloy layer, and the rare earth aluminium alloy layer should be 100  $\mu\text{m}$  to 120  $\mu\text{m}$ .

4) The pre-treated steel surface should be sprayed within 2 hrs on the surface. It shall be coated within 8 hrs at most under sunny and normal atmospheric conditions.

5) When the relative humidity of the air is greater than 85% , the surface temperature of the steel plate is 3 °C lower than the dew point of the atmosphere, or the ambient temperature

is lower than 5 °C , spraying shall not be carried out.

- 6) Spraying shall be uniform and performed several times. The thickness of each spraying coating should be in the range of 25 µm and 60 µm. Spraying beams of adjacent sprayings shall be crossed vertically.
  - 7) Metal spraying coating shall be sealed in good time with organic coatings after being checked and confirmed as qualified. Dust on the surface of the metal spraying coating shall be cleaned off before painting. Coating should be carried out when metal spraying coating reaches a certain temperature.
- e) Metal coating quality inspection shall meet the following requirements:
- 1) The metal coating's appearance shall be inspected. The coating surface shall be uniform, without impurities, peeling, bubbles, holes, irregularities, unstable metal melt coarse particles, debris, exposed substrate spots or cracks. Spraying shall be stopped when obvious defects in coating appearance are found. When a small amount of inclusion is found, it can be scraped off with cutting tools. When the defect area is large, the spraying shall be removed and re-spraying shall be performed.
  - 2) Thickness measurement of the metal coating and the testing method of binding performance shall meet requirements.
- f) Construction of the sacrificial anode cathodic protection system shall meet the following requirements:
- 1) The sacrificial anode cathodic protection system shall be combined with coating protection.
  - 2) Penstocks with the sacrificial anode cathodic protection system shall be electrically insulated from other metal structures in water.
  - 3) The following requirements shall be met before construction of the sacrificial anode cathodic protection system:
    - Measurement of self-potential of penstocks.
    - It is confirmed that field environmental conditions are consistent with design documents.
    - It is confirmed that instruments and materials used in the protection system are consistent with the design documents.
  - 4) Arrangement and installation of the sacrificial anode shall meet the following requirements:

- The surface of sacrificial anodes shall not have paint and oil stains.
  - Arrangement and installation of sacrificial anodes shall not affect the normal operation of the penstock, and shall be able to meet the design requirements for the protection potential of the penstock.
  - Coating at the connection position between the sacrificial anode and the penstock shall be removed and the metal substrate shall be exposed, and the area should be about 0.01 m<sup>2</sup>.
  - The sacrificial anode shall be in short-circuit connection with the steel tube through steel core. They can also be connected with cables or mechanically-connected.
  - Sacrificial anodes shall be avoided in high stress and high fatigue loading areas of steel tubes.
  - When sacrificial anodes are installed by welding, the welding joints shall be free of burrs, sharp edges and false welding.
  - After sacrificial anodes are installed, the surface of the installation area shall be cleaned and re-coated according to technical requirements, and the surface of sacrificial anodes shall not be polluted during repainting.
- g) Quality check of the sacrificial anode cathodic protection system shall meet the following requirements:
- 1) After the construction of the sacrificial anode cathodic protection system is completed, the completed installation drawings for the sacrificial anode shall be submitted and shall verify whether the actual installation quantity, location, and connection of the anode meet the requirements.
  - 2) Before the protection system is installed and delivered for use, the protection potential of the penstock shall be measured and ensured that it meets design requirements.
  - 3) After the sacrificial anode can be used normally, the equipment and components of the protection system shall be regularly inspected and maintained to ensure effective operation within the service life.
  - 4) The user shall measure and record the protective potential of the penstock at least once every six months. When the measured results do not meet the requirements, the reason shall be found out in good time and measures shall be implemented.

**8.4.6** The hydrostatic testing of penstocks shall be implemented in accordance with the following



requirements:

- a) The hydraulic pressure testing and test pressure of penstocks and bifurcated pipes shall be carried out according to drawings or design technical documents.
- b) Safety measures and plans shall be worked out before the hydraulic testing of penstocks and bifurcated pipes.
- c) The test bulkhead shall be determined through design calculation.
- d) When the pressure is tested, the water temperature shall be above 5 °C.
- e) One end of the breathing tube shall be installed at the highest position when the penstock and bifurcated pipe are tested.
- f) When the height difference is greater than 100 m during a penstock hydrostatic test, the vacuum breakage valve should be installed at the top of the penstock section.
- g) The hydrostatic test shall be conducted after the penstock and bifurcated pipe are manufactured or installed and inspected as qualified. Before water is filled, the fixture, temporary support, bracket, and lifting equipment shall be relieved, and defects of welding scars and scratches on the structure shall be repaired and polished.
- h) Water pressure of the penstock and bifurcated pipe shall be increased step by step, and tested level by level. When the rated working pressure is reached, maintain the pressure for more than 30 min. If the pressure gauge needle remains stable and no needle flutter or other abnormal conditions occur, continuous pressure adding is allowed. The pressure rate cannot be greater than 0.3 MPa/min. When the pressure is greater than 10 MPa, the pressure rate cannot be greater than 0.2 MPa/min. When the maximum pressure is reached, maintain the pressure for more than 30 min. At this time, the pressure indicated by the pressure gauge should remain unchanged. Then, the maximum pressure is lowered to the working pressure, maintain the pressure for more than 30 min. There shall be no seepage, concrete cracks, abnormal displacement of piers and other abnormal conditions during the entire test.
- i) After the water pressure testing of penstock and bifurcated pipe is completed, the overflow control valve for the booster system is discharged to the self-weight pressure of the water in the penstock at a speed of no more than 0.5 MPa/min by stages, and then the air tube valve at the upper end of the penstock section is opened for drainage operation.
- j) When problems occur in the testing system and need to be dealt with, the system pressure shall be discharged to the dead weight pressure via the relief control valve for the booster system, and is then operated according to the specific situation.

- k) When welding, hot cutting, carbon arc gouging, hot rectification and other operations are required, the water shall first be emptied from the pipe.

## 9 Environmental protection

### 9.1 Basic provisions

9.1.1 Environmental protection shall include pollution prevention, ecological protection, occupational health protection, environmental management and monitoring.

9.1.2 The environmental protection measures proposed based on project environmental impact assessment, soil and water conservation scheme, environmental protection design and soil and water conservation measures design shall be implemented. Optimization shall be carried out based on the premise of meeting the environmental protection requirements according to the specific construction conditions.

### 9.2 Pollution prevention and control

9.2.1 Pollution control measures shall be adapted to local conditions and coordinated as a whole to meet requirements of environmental function and sensitive target protection.

9.2.2 Wastewater, waste gas, solid waste, and noise pollution prevention and control facilities shall be reasonably arranged combined with the general construction layout, pollution sources, pollutant discharge methods and the environmental conditions of the project.

9.2.3 Wastewater treatment shall meet the following requirements:

- a) Wastewater from construction of an SHP station includes wastewater generated from sand and gravel processing, concrete mixing and washing, cement grouting, foundation pit (for concrete roughing, silo cleaning and maintenance), foundation pore-making, mechanical equipment cleaning and maintenance, and domestic sewage from the construction workers.
- b) Discharge of wastewater produced during construction and domestic sewage shall meet the requirements.
- c) The treatment rate of wastewater (sewage) shall be no lower than that stipulated by the local government where the project is located, and shall be no lower than 80% if there are no relevant specifications.
- d) When the drinking water source protection zone is located near the construction area, the arrangement of the waste water discharge outlet shall be consistent with relevant regulations. It is forbidden to set up sewage outlets in drinking water source protection zones; if sewage outlets

are set up near the protection zones, the water body in the protection zones shall not be polluted.

- e) When the natural sedimentation method is used to treat wastewater from sand and gravel processing systems, sufficient sedimentation time shall be guaranteed and the sedimentation tank shall be cleaned regularly; mud should be dried and transported to the waste landfill.
- f) The treatment of wastewater from a concrete mixing system shall be combined with the project layout and a wastewater sedimentation tank should be set up nearby. The supernatant can be recycled and the wastewater should be neutralized.
- g) Drainage systems in production and living areas shall be kept unhindered and the main drains shall be hardened. Rainwater shall not be imported into sedimentation tanks, septic tanks, oil separation ponds, refuse dumps and dry mud storage sites.
- h) Waterproofing, seepage-proofing and loss-proofing measures shall be implemented in production and living areas where oil and electrolytes are stored.
- i) Wastewater from canteens and bathrooms should be intercepted and discharged through oil sequestration tanks (including a complete set of oil-water separation devices) or septic tanks.
- j) Domestic sewage shall not be discharged at will. Sewage shall be transported in good time when a septic tank is used to treat sewage. When mobile environmental toilets are used, sewage and faeces shall be centrally recycled for harm-free treatment.

**9.2.4** Prevention and control of exhaust gas pollution shall meet the following requirements:

- a) Prevention and control measures shall be implemented for air pollution, such as dust from earthwork excavation, blasting, sand and stone processing, concrete mixing, material transportation, storage, and waste residue transportation, as well as for waste gas from asphalt processing, fuel oil, construction machinery, vehicles and domestic coal combustion.
- b) Ambient air quality in the affected area shall meet the requirements for corresponding functional areas after preventive measures are taken.
- c) Water spraying and ventilation measures shall be taken in the construction area of an underground powerhouse and diversion tunnel to improve air diffusion conditions of underground caverns. Construction labourers shall be protected in accordance with the relevant provisions.
- d) The wet crushing process should be adopted for aggregate processing, so as to reduce the drop height during transferring and seal the dust source.
- e) Transportation of fine particles such as cement, lime, and fly ash should be carried out using

sealed tank cars. Tarpaulins shall be used to cover the open truck during transportation. Materials shall be prevented from scattering during loading and stacking.

- f) Construction roads shall be regularly maintained, and sprinkler trucks or artificial sprinklers shall be provided for dust-proofing.
- g) Drilling equipment with dust traps should be preferentially used for drilling and blasting operations. Wet drilling or orifice spray shall be adopted when equipment without a dust catching device is used. Loose blasting and water spraying for dust fall shall be adopted in open-air blasting operations; sprinkler spray shall be adopted in underground works.

**9.2.5 Solid waste disposal shall meet the following requirements:**

- a) Solid waste disposal objects shall include domestic garbage, construction garbage, and production wastes, and the disposal shall be recycling, minimized, and harmless.
- b) Garbage bins or garbage stacking points shall be arranged around the camp buildings. Domestic wastes shall be collected in a centralized manner, properly transported, and disposed of in a centralized manner, and preferably by means of landfills. Landfill sites shall be kept away from drinking water source and fishery water area.
- c) Construction wastes shall be disposed of in a centralized manner, and the renewable resources should be recycled; hazardous solid waste shall be treated in accordance with relevant regulations.

**9.2.6 Noise control shall meet the following requirements:**

- a) Noise control measures for construction machinery and equipment, aggregate processing equipment, transport vehicles, and blasting shall be implemented.
- b) Noise control shall meet the sound environment requirements in project area.
- c) Noise source control and transmission control shall be carried out according to the type of noise source, the intensity of noise, and the objects affected by noise. Personal protective measures shall be taken when necessary.
- d) Ambient noise control at the construction site's boundary shall meet the requirements of 70 dB (A) during the day and 55 dB(A) at night. Noise control for sensitive buildings in the construction affected area shall meet requirements of 55 dB(A) during the day and 45 dB(A) at night.
- e) Priority shall be given to equipment with less noise. To control mechanical noise, the maintenance of mechanical equipment shall be emphasized. Main mechanical equipment shall be arranged far away from sensitive buildings, and noise reduction and vibration reduction

measures shall be adopted.

- f) To control the noise of transport vehicles, construction road maintenance and management shall be strengthened. Signs such as speed limit and no honking shall be set up in sensitive areas. Noise barriers shall be set up when noise is unavoidable in sensitive areas, such as schools and hospitals.
- g) Engineering blasting shall employ low-noise blasting technology and shall not be implemented at night.
- h) Blasting design shall be carried out according to rock characteristics to reasonably control single-shot charge quantity; bench blasting construction should be adopted and the blasting resistance line should be rationally designed; it is forbidden to use bare blasting charges for blasting operations.
- i) At the construction site's boundary, the maximum sound level for sudden noise at night shall not exceed the limit value of field boundary noise by more than 15 dB(A).
- j) Provisions on labour protection shall be implemented for construction workers in high-noise positions and personal protective measures shall be taken.

### 9.3 Ecological protection

9.3.1 Ecological protection shall be designed with consideration given to coordinated development of ecological environment protection and social economy, and shall follow the principle of maintaining ecological functions to meet the requirements for regional sustainable development.

9.3.2 In the implementation phase, ecological protection measures shall be optimized according to the construction characteristics and ecological conditions of the construction area, and be simultaneously implemented along with the main construction.

9.3.3 It is forbidden to cross the red lines for ecological protection in the construction area and the influenced area or to damage the ecological environment outside the construction site.

9.3.4 Soil erosion and control shall meet the following requirements:

- a) Soil and water conservation measures shall be implemented in construction areas in accordance with soil and water conservation plans and designs.
- b) The land of the construction site shall be used in a rational way to control and reduce disturbance and damage to the original landform, surface vegetation and water system, and shall protect the original surface vegetation, surface soil and crust layer.

- c) Ordered excavation and timely support shall be carried out according to the designed opening line and slope ratio to prevent vegetation damage outside the opening line caused by slope instability.
- d) Selection of the soil (stone and slag) spoil area and soil (stone and material) borrow area shall meet soil and water conservation requirements.
- e) Engineering waste soil (slag) shall be first intercepted and then abandoned, and the slag shall be rationally used to reduce the quantity of waste slag.
- f) Measures, such as blocking, slope protection, water interception and drainage, shall be taken for excavation, dumping and stacking sites.
- g) Surface mellow soil peeled off during material fetching shall be temporarily stocked and set aside as backfill soil. Land levelling shall be carried out in good time after materials are fetched, and vegetation shall be restored or reclaimed according to local conditions.
- h) Waste residues from the foundation excavation for the dam and powerhouse shall be transported to the designated slag field in time to prevent being dumped into the river course. The construction method of “blocking first and discarding later” shall be adopted for ash and slag stacking. Soil and stone slags with various physical and chemical properties shall be stacked in different zones. The top platform of the slag yard, bench platform, and slope shall be levelled and covered with soil to restore vegetation or reclaimed after slags are abandoned.
- i) Waste slags excavated along the diversion system construction line shall be stacked according to design requirements for soil and water conservation, and vegetation shall be restored according to topographic and soil conditions.
- j) Slope protection and drainage shall be carried out for construction roads in accordance with soil and water conservation requirements. Roadside trees should be planted on both sides of permanent roads.
- k) Land reclamation shall be carried out in time for the construction site, and soil and water conservation measures shall be adopted to restore its original function. Greening and landscaping work shall be performed for the dam, power plants, water diversion systems, and office & living areas.

**9.3.5 Protection of animals and plants shall meet the following requirements:**

- a) Terrestrial plant protection and restoration objects shall include important ecosystems (including vegetation, forests, grasslands and wetlands), nature reserves, forest parks, natural forest protection projects, and rare and endangered plants in the engineering-affected areas.

- b) Engineering construction shall not damage vegetation outside the construction area. Rare or endangered species shall be transplanted to places outside the construction area according to the ecological suitability requirement when relocation for conservation measures is taken. Rare or endangered species shall be listed and registered with warning signs when in-situ conservation measures are taken.
- c) Engineering construction shall not hurt protected wild animals. Illegal killing, domestication, reproduction, sale of rare and endangered wildlife, and destruction of major habitat and breeding sites for protected wild animals are prohibited.
- d) Protection measures shall be implemented in accordance with the design requirements for environmental protection, if construction will be implemented in areas with important economic values and rare & endangered aquatic organisms, or the river closure period will impact the survival, reproduction and migration of fishes.
- e) It is forbidden to use prohibited fishing gear or methods in order to fish in prohibited fishing areas and during prohibited fishing periods, and it is forbidden to set up nets to catch birds on migratory routes, to catch young birds and to collect eggs in wetlands.
- f) Assistance shall be provided if it is found that protected wildlife is being threatened or hurt near the project area. The information shall be reported to the local environmental or forestry authorities in a timely manner.
- g) Influence of project construction on nature reserves shall be in line with the regulations about natural reserves.

#### 9.4 Environmental management and monitoring

9.4.1 Environmental management shall be carried out synchronously with project management during the construction period.

9.4.2 Environmental management shall mainly include:

- a) Compiling the implementation plan for environmental protection and implement various environmental protection measures.
- b) Establishing rules and regulations for pollutant emission control, ecological protection and environmental monitoring.
- c) Controlling the discharge of pollutants and protect the ecological environment according to regulations.
- d) Checking the implementation progress and quality of environmental protection measures.

- e) Conducting environmental monitoring, analysing the environmental quality and development trend in construction areas and relevant affected areas, and carrying out post-environmental impact assessment or putting forward requirements for optimizing environmental protection measures based on monitoring and assessment results.
- f) Formulating plans for the disposal of potential environmental pollution accidents, and investigating and processing environmental pollution and ecological damage accidents.

**9.4.3** In-time environmental monitoring shall be carried out during construction. The monitoring organization shall perform monitoring work in a timely manner based on the plan and in accordance with the project's progress; monitoring results shall be collated, analysed, fed back, filed and reported in a timely manner. Emergency pollution incidents or serious ecological damage accidents shall be monitored and reported in a timely manner.

**9.4.4** During implementation of environmental protection measures, the project owner shall verify, monitor and truthfully record the construction and commissioning of project environmental protection facilities.

## **9.5 Occupational health protection**

**9.5.1** Occupational health and safety shall meet the country's occupational health and safety regulations.

**9.5.2** Special plans for occupational health and safety during the construction period shall be prepared according to the characteristics of the project.



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

**Pre-splitting blast parameters of rock foundation excavation**

**A.1** Hole spacing of blastholes shall be calculated according to the Formula (A.1):

$$a = (7 \sim 12)D \quad \dots\dots\dots(A.1)$$

where

*a* is the hole spacing of blastholes, in mm;

*D* is the Diameter of drill holes, in mm.

**A.2** Decoupling coefficient.

The decoupling coefficient shall be shall be calculated according to the Formula (A.2):

$$D_d = D/d = 2 \sim 5$$

$$\text{or } D = (2 \sim 5)d \quad \dots\dots\dots(A.2)$$

where

*D<sub>d</sub>* is the decoupling coefficient;

*d* is the cartridge diameter; *d* = 20 mm to 30 mm generally.

**A.3** Linear charge density's empirical formula.

a) Calculate according to the rock's compressive ultimate strength and the spacing between adjacent holes:

$$Q_x = 0.589a\sigma_p^{0.5} \quad \dots\dots\dots(A.3)$$

where

*Q<sub>x</sub>* is the linear charge density (g/m), counting the hole's total length;

*a* is the blasthole hole spacing, in mm;

*σ<sub>p</sub>* is the rock's compressive ultimate strength, in MPa.

Application scope:

$$\sigma_p = 20 \sim 150 \text{ (MPa)}$$

$$a = 450 \sim 1\,200 \text{ (mm)}$$

- b) Calculate according to the rock's compressive ultimate strength and drill hole radius ( $Q_x$  is the depth after deducting the length of plugged holes):

$$Q_x = 9.22 r^{0.38} \sigma_p^{0.53} \dots\dots\dots (A.4)$$

where

$r$  is the radius of drill holes, in mm.

Application scope:

$$\sigma_p = 10 \sim 150 \text{ (MPa)}$$

$$D = 2r = 46 \sim 170 \text{ (mm)}$$

**Appendix B**  
**(Informative)**  
**Classification table of surrounding rock geology in underground hydropower engineering**

**Table B.1 Classification table of surrounding rock geology in underground hydropower engineering**

Type	Name	Surrounding rock's main engineering characteristics		Active state of underground water	Surrounding rock stability of the excavation face's unlined tunnels	Basis of Calculation for rock pressure	Temporary supporting measures (suggested)
		Rock condition	Structural plane's characteristics				
I	Stable	The rock is fresh, integral and the influence of the geological structure is slight. The joints and fissures are undeveloped or slightly developed and most of them are closed and without long extension. The rock does not have or rarely has weak structural planes and the plane's width is generally less than 0.1 m; The rock is a blocky integral structure or blocky masonry structure.	The structural plane has no unstable assemblage; The direction of fault layers is nearly orthogonal with the tunnel line.	Tunnel wall is dry or slightly damp. There is slight water leakage along several joints and fissures	Well shaped and without falling blocks	Disregard rock pressure	May be left unsupported generally
II	Basically stable	The rock is fresh or slightly weathered and generally is influenced by geological structures. The joints and fissures are slightly developed. The rock has a few weak structural planes whose width are less than 0.5 m; The rock is a masonry structure or stratiform structure.	Structural plane's assemblages are basically stable. There are unstable assemblages only in local parts. The direction of weak structural planes such as faults cross obliquely or orthogonally.	Tunnel wall is damp. There is water leaking and dropping along some joints, fissures or weak structural planes.	The tunnel is badly shaped in local parts and there are some blocks falling. The tunnel is slightly collapsed after long time exposure in local parts	Rockfall load shall be considered in some parts. Ultimate balance theory or structural plane analysis method may be used to calculate.	Need to be supported in local parts

Table B.1 (continued)

Type	Name	Surrounding rock's main engineering characteristics		Active state of underground water	Surrounding rock stability of the excavation face's unlined tunnels	Basis of Calculation for rock pressure	Temporary supporting measures (suggested)
		Rock condition	Structural plane's characteristics				
III	Relatively poor stability	The rock is slightly or moderately weathered and is seriously influenced by geological structures. The joints and fissures are developed and some of them are open and filled with mud. The rock has many weak structural planes whose width are up to 1 m; The rock is a bubbly mosaic structure	Most of the structural plane's assemblages are not favourable for the surrounding rock's stability; The direction of main weak structural planes such as faults is oblique or parallel to the tunnel line.	Ground water activity is significant. There is water leaking, dropping or gushing linearly along the joints, fissures or fault zones	The shape is in a slightly bad state. There will be small scale collapse if the tunnel has no supports. Sometimes local instability occurs at high side-walls	Combined with geological analysis, the ultimate balance theory or granular theory may be used to calculate	Need to be supported generally
IV	Poor stability	The rock condition is the same as Class III but there are more weak structural planes whose widths are up to 2 m. Parts of the joints and fissures are developed; The rock is a bubbly mosaic structure. In some parts it is a bubbly crushed structure.	The structural plane's assemblages are not favourable for the surrounding rock's stability; The direction of weak structural plane such as faults shall be oblique or parallel to the tunnel line.	Ground water activity is significant. There is water leaking, dropping or gushing linearly along the joints, fissures or fault zones	The shape is in a bad state. Generally the top arch will be over-excavated because of collapse. Large collapse may occur if there is no support. Instability occurs at the side-walls.	Use granular theory	Must be supported

Table B.1 (continued)

Type	Name	Surrounding rock's main engineering characteristics		Active state of underground water	Surrounding rock stability of the excavation face's unlined tunnels	Basis of Calculation for rock pressure	Temporary supporting measures (suggested)
		Rock condition	Structural plane's characteristics				
V	Unstable	<p>1. Lithoid surrounding rock: The rock is strongly or totally weathered and is seriously influenced by geological structures. The joints and fissures are highly developed. The rock has many weak structural planes whose widths are up to 1 m; The rock is a gravel shaped mosaic structure The fault-fracture zone is wider than 2 m and is mainly composed of fault gouges, mylonite and breccia. Most of the fractures are filled with mud. The rock is a granular structure which is gravel, sand or debris shaped;</p> <p>2. Loose layers of earth, sand, accumulation and generally gravel, pebble, gravelly soil.</p> <p>3. Strongly extruded large fault zone. The fractures are disordered and are earth mixed with rock or rock mixed with earth.</p>	<p>The structural planes are disordered and the assemblages are unstable.</p> <p>The direction of main weak structural planes such as faults is parallel to the tunnel line.</p>	<p>Ground water activity is intense. There is a large amount of leakage and the leakage often causes collapses.</p>	<p>The shape is in a very bad state. The surrounding rock collapses easily. Even the ground will sink or rise.</p>	<p>Use granular theory</p>	<p>Supports shall be strengthened</p>

## Appendix C (Informative)

### Parameters of smooth wall blasting and pre-splitting blasting in tunnel excavation

**Table C.1 Parameters of smooth wall blasting**

Rock type	Spacing between periphery holes (mm)	Resistance lines of periphery holes (mm)	Linear charge density (g/m)
Hard rock	550~650	600~800	300~350
Medium hard rock	450~600	600~750	200~300
Soft rock	350~450	450~550	70~120
<b>NOTE</b> Blasthole diameter shall be 40 mm~50 mm; cartridge diameter shall be 20 mm~25 mm.			

**Table C.2 Parameters of shallow hole pre-splitting blasting (hole depth  $\leq 5$  m)**

Rock type	Spacing between periphery holes (mm)	Resistance lines of periphery holes (mm)	Linear charge density (g/m)
Hard rock	400~500	400	350~400
Medium hard rock	400~450	400	200~250
Soft rock	350~400	350	70~120
<b>NOTE</b> Blasthole diameter shall be 40 mm~50 mm; cartridge diameter shall be 20 mm~25 mm.			

## Appendix D (Informative)

### Combined bolting and shotcreting of tunnels

**D.1** The type of combined bolting and shotcreting shall be determined by on-site strain observation according to the surrounding rock's characteristics, section size and construction methods.

**D.2** The selection of anchor bolt material and type.

- a) No.20 manganese silicon steel or No.5 steel should be chosen as bolt material.
- b) Cement-and-grouted steel bolts shall be used preferentially. Slot-and-wedge bolts, shell-expanding bolts or resin anchor bolts may be used as well according to the construction conditions.

**D.3** Anchor bolt parameters and arrangement

- a) Anchor bolt parameters shall be determined by engineering analogy or tests according to the construction conditions. Generally, the following requirements may be referred to:
  - 1) System anchor bolt depth shall be 1.5 m to 3.5 m. The spacing shall be 1/2 of the anchor bolt's depth and shall be no larger than 1.5 m. A single anchor bolt's anchorage force shall be no less than 50 kN. Anchor bolts arranged locally shall be anchored into stable rock mass. The depth and spacing shall be determined according to the practical situation.
  - 2) Deep anchor bolts whose length are longer than 5 m and pre-stressed anchor cables shall be specially designed in combination with the permanent supports.
  - 3) Generally, the anchor bolt's diameter is between 16 mm and 25 mm.
- b) Anchor bolts shall be arranged to form a large angle with the rock's main structural planes. If there is no obvious structural plane, the anchor bolts may be perpendicular to peripheral contour lines.
- c) Anchor bolts may be combined by steel bars, section steel or metal netting to prevent the falling of rock and the grid size should be 50 mm × (50~80) mm × 80 mm.

**D.4** The installation of metal netting or steel bar netting shall meet the following requirements:

- a) Metal netting shall be laid on the rock surface and the gap shall be no less than 30 mm.
- b) The grid size of metal netting used in shot concrete should be 200 mm × (200~300) mm × 300 mm.

The steel bar diameter should be 4 mm to 10 mm.

- c) Metal netting shall be firmly connected with the anchor bolts.

**D.5** Checking of anchor bolts shall meet the following requirements:

- a) Slot-and-wedge type anchor bolts shall be tightened again 24 hrs after installation and the working station shall be checked at regular times.
- b) The anchor bolt's anchorage force may be checked by sampling (take 300 anchor bolts as a group and take 3 samples in each group. If the surrounding rock condition or raw material has changed, another group of samples shall be tested). The sampling rate shall be no less than 1%. The average value shall be no lower than the design value. The average value of any sampling group shall be no lower than 90% of the design value.
- c) During construction, the position, direction, depth, bore diameter, cleaning quality, mortar properties and grouting compactness shall be checked respectively.

**D.6** The installation of mortar anchor bolts shall meet the following requirements:

a) Mortar:

- 1) Medium-fine sand should be used and the maximum diameter shall be no larger than 3 mm.
- 2) Common Portland cement should be used with strength grade higher than 32.5.
- 3) The weight ratio between the cement and sand should be 1 : 1 to 1 : 2 and the water cement ratio should be 0.38 to 0.45.

b) Installation:

- 1) The arrangement of drill holes shall meet the design requirements. The error of the hole position shall be no larger than 200 mm. The error of the hole depth shall be no larger than 50 mm.
- 2) Before grouting, the holes shall be cleaned by high pressure air or water.
- 3) The mortar shall be uniformly mixed and shall be used immediately after mixing.
- 4) The mortar shall be grouted by grouting devices and the mortar shall be grouted fully.
- 5) Any impacting shall be avoided after the installation.



**D.7** The material used in shotcreting and the material's properties shall meet the following requirements:

- a) The concrete strength grade shall be no lower than C20.
- b) Common Portland cement whose grade is no lower than 32.5 should be used.
- c) Medium, coarse sand and gravel whose diameter is 5 mm to 15 mm shall be chosen. Other requirements regarding the aggregate shall comply with of 4.5.12 and 4.5.13.
- d) The accelerating agent's initial setting time shall be no longer than 5 min while final setting time shall be no longer than 10 min.
- e) Mix proportion may be determined according to the following data based on experience:
  - 1) The weight ratio of cement and sand should be 1 : 4 to 1 : 4.5.
  - 2) Sand ratio should be 45% to 55%.
  - 3) Water cement ratio should be 0.4 to 0.5.
  - 4) Amount of accelerating agent to be mixed should be 2% to 4% of the cement's dosage.

**D.8** The process of shotcreting shall meet the following requirements:

- a) Before spraying, the rock face shall be washed clean and any weak broken rock shall be cleared away.
- b) The spraying shall be done by sections and generally the spacing shall be no larger than 6 m. The order of spraying shall be from bottom to top.
- c) The next spraying shall be done after the final set of concrete. If the spraying is done one hour after the final set, the concrete surface shall be washed by air and water.
- d) Spraying thickness: 40 mm to 60 mm for the sidewall, 20 mm to 40 mm for the arch.
- e) The rock face shall be watered and maintained 2 hrs to 4 hrs after spraying. Generally the maintenance shall last for 7 days to 14 days.
- f) The time from the concrete spraying to the next cycle's blasting shall be determined by tests and generally shall be no less than 4 hrs. The concrete shall be checked after blasting. If there is any fissure, the interval time of blasting or exploding parameters shall be adjusted.

- g) In normal conditions, the springback of the arches is 20% to 30% and the springback of the sidewalls is 10% to 20%.

**D.9** The quality of the shotcrete shall meet the following requirements:

- a) The shotcrete surface shall be flat, smooth and have no flaws such as dry spots, loose areas, hollow voids, fissures and exposed bars. If there are any flaws, remedial measures shall be taken. The thickness of spraying shall meet the design requirements.
- b) The strength of shotcrete shall be controlled according to the following requirements:
  - 1) One group of specimens shall be taken per 50 m<sup>3</sup> of shotcrete. If there is any change of the material or mix proportion, one more group shall be taken. There shall be three specimens in each group and the specimens shall be taken uniformly.
  - 2) Average compressive strength shall be no lower than the design standard strength. The average strength of any group of specimens shall be no lower than 85% of the design standard strength.
  - 3) Specimens should be taken by the method of cutting.

**Appendix E**  
**(Informative)**

**Calculated load of common frameworks and supports**

E.1 The self-weight of frameworks and supports shall be determined according to the design drawings. The weight of wood per unit volume may be calculated as follows: conifers: 6 kN/m<sup>3</sup>, including larches: 8 kN/m<sup>3</sup> and broadleaf: 8 kN/m<sup>3</sup>.

E.2 Steel bar self-weight shall be determined according to the design drawings. Generally, reinforced concrete of plate and beam structures per cubic meter may be calculated as 1.1 kN/m<sup>3</sup> for plates and 1.5 kN/m<sup>3</sup> for beams.

E.3 Self-weight of fresh concrete shall be calculated as 24 kN/m<sup>3</sup>.

E.4 Load of people and transport machines: when calculating the frameworks or the secondary beams which bear the framework directly, the uniform load is 2.5 kN/m<sup>2</sup> and a concentrated load of 2.5 kN shall be used in checking calculations. Compare the bending moments in two calculations and adopt the larger moment. When calculating the members which bear secondary beams directly, the uniform live load is 1.5 kN/m<sup>2</sup>. When calculating the support columns and other supporting members, the uniform live load is 1.0 kN/m<sup>2</sup>.

E.5 Both the horizontal and vertical loads caused by vibrating the concrete should be 1.0 kN/m<sup>2</sup>.

E.6 The lateral pressure of fresh concrete acting on the framework: when using an immersion vibrator, the lateral pressure may be calculated according to the Formula(E.1):

$$P = 8 + 24Kv^{\frac{1}{2}} \dots\dots\dots ( E.1 )$$

where

*P* is the lateral pressure of concrete acting on the framework, in KN/m<sup>2</sup>;

*K* is the temperature correction coefficient, one may refer to Table E.1;

*v* is the concrete casting speed, in m/hr.

Lateral pressure's calculated distribution graph is shown in Fig E.1:

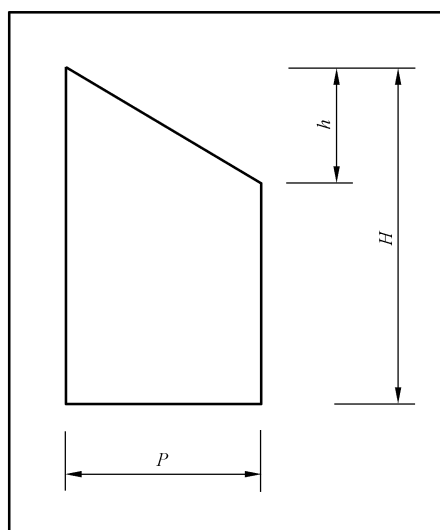


Figure E.1 Side pressure calculation layout plan

where

$H$  is the thickness of the concrete lift in flowing state, in m;

$h$  is the  $h = \frac{P}{\gamma}$ ;

$\gamma$  is the concrete's volume weight, take 24 kN/m<sup>3</sup>.

Table E.1 Temperature correction coefficient K

Temperature (°C)	5	10	15	20	25	30	35
K	1.53	1.33	1.16	1.00	0.86	0.74	0.65
<p><b>NOTE</b> Temperature here means the concrete temperature. In normal conditions which means no measures are taken to change the concrete temperature when poured on to formwork, the air temperature at the time of concrete casting may be used as the temperature.</p>							

E.7 For horizontal dynamic loads caused by placing concrete one may refer to Table E.2.

Table E.2 Horizontal dynamic load

Unit: kN/m<sup>2</sup>

Method of placing concrete into the framework	Horizontal load acting on lateral framework
Flowing out directly from chute tumbling barrels or concrete conduits	2
Poured by transport containers whose capacity is less than 0.2 m <sup>3</sup>	2
Poured by transport containers whose capacity is between 0.2 m <sup>3</sup> ~ 0.8 m <sup>3</sup>	4
Poured by transport containers whose capacity is larger than 0.8 m <sup>3</sup>	6

**Appendix F**  
**(Informative)**

**Calculation methods for average concrete strength  $m_{fcu}$ , standard deviation  $S_{fcu}$  and strength assurance rate P**

**F.1 Average strength  $m_{fcu}$**

Average strength  $m_{fcu}$ —Eigenvalue of the overall strength, which means the compressive strength’s arithmetic mean value of  $n$  groups of concrete specimens with the same strength grade:

$$m_{fcu} = \frac{\sum_{i=1}^n f_{cu,i}}{n} \dots\dots\dots ( F.1 )$$

where

$m_{fcu}$  is the average strength of  $n$  group of specimens, in MPa;

$f_{cu, i}$  is the average compressive strength of each group of specimens, in MPa;

$n$  is the number of specimen groups.

**F.2** The calculation formula of the standard deviation  $\sigma_0$  of the acceptance batch concrete strength is the same as the calculation formula of  $\sigma$ . They are all calculated according to the Formula (F.2):

$$\sigma_0(\sigma) = \sqrt{\frac{\sum_{i=1}^n f_{cu,i}^2 - nm_{fcu}^2}{n - 1}} \dots\dots\dots ( F.2 )$$

where

$f_{cu, i}$  is the strength value of Group  $i$  specimens, in MPa;

$m_{fcu}$  is the average strength of  $n$  groups of specimens; in MPa;

$n$  is the the number of groups of specimens.

When the standard deviation of the compressive strength ( $\sigma$ ) is less than 2.5 MPa, calculate the concrete design strength standard value ( $f_{cu,k}$ )  $\geq$ C20, and  $\sigma < 2.0$  MPa, then  $\sigma = 2.0$  MPa shall be taken; When calculate concrete design strength standard value ( $f_{cu,k}$ )  $<$ C20, and  $\sigma < 1.5$  MPa, then

$\sigma = 1.5$  MPa shall be taken.

**F.3 Strength assurance rate  $P$**

a) Calculation of strength assurance coefficient  $t$

$$t = \frac{m_{f_{cu}} - f_{cu,k}}{\sigma} \dots\dots\dots ( F.3 )$$

where

$t$  is the probability degree coefficient;

$m_{f_{cu}}$  is the average strength of concrete specimens; in MPa;

$f_{cu,k}$  is the design strength standard value of concrete, in MPa;

$\sigma$  is the standard deviation of concrete strength, in MPa.

b) The relationship between guarantee rate  $P$  and probability degree coefficient  $T$  is found in Tables F.1 and Figure F.1.

**Table F.1 Relationship between assurance rate and assurance coefficient**

Assurance coefficient	0.60	0.70	0.80	0.842	0.95	1.04	1.282	1.50	1.645	2.0	3.0
Assurance rate $P$ (%)	73	76	79	80	83	85	90	93.3	95	97.5	99.9

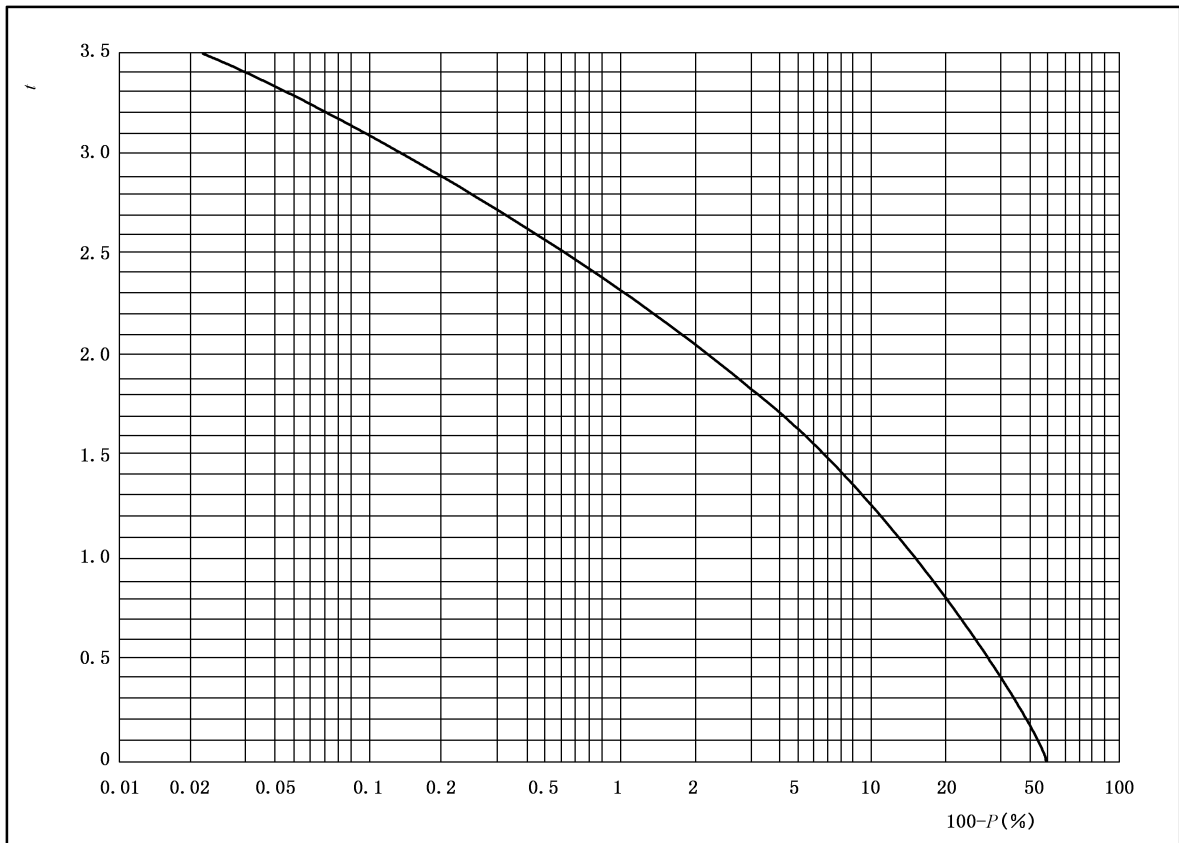


Figure F.1 Relationship between probability degree coefficient ( $t$ ) and guarantee rate ( $P$ )

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