CFRD/D001--2008

Guidelines for Design
High Concrete Face Rockfill Dam

(Draft)

Sponsor:

CFRD INTERNATIONAL SOCIETY

FOREWORD

The concrete face rockfill dam (CFRD) has been constructed widely all over the world now its stability, taking full advantage of local excavated materials and constructed simply, and economically, and best adaptability to geology and topography, operation safely and easily remedy. CFRDs > 100m are 200 or so spreading around the world ; the extra high CFRDs (> 150 m) are much more built or underway such as Shuibuya (233m, China), Jiangpinghe (221m , China), La Yesca (210m, Mexico), Bakun (205m , Malaysia), Campos Novos (202m , Brazil), Guxian (199m, China), Kárahnjúkar (196m, Iceland), El Cajon (189m, Mexico), Aguamilpa (187m, Mexico), Sanbanxi (186m, China), Barra Grande (185m, Brazil), Mazar (185m, Ecuador), Hongjiadu (179.5m, China), Tianshengqiao I (178m, China), Tankeng (162m, China) and Areia (160 m, Brazil), Zipingpu (158m, China), Bashan (155m, China), Jilingtai (152m, China), etc.

Cracks and ruptures at face slabs and high leakages (> 1,000 liter/s) currently recorded at many high CFRDs in the world shown that different factors have been affected CFRD behavior. However such ruptures or cracklings at face slabs of a CFRD shall never impact its stability and safety. Nevertheless we must pay great attention to these problems since the CFRD construction has entered into very high construction stage, more or larger cracks may increase amount of leakage from reservoirs, wasting water resources for generating power, etc. We ought to resolve these problems in CFRD design and construction.

CFRD INTERNATIONAL SOCIETY hereby organized CFRD experts from relative countries for comprehensive summing up the experiences of constructions of world concrete face rockfill dam (CFRD) and studied the technical problems occurred recent years in the constructions of world

high and very high CFRDs, and presented the effective measures for overcoming them in May 2007 so as to meet the requirements for development of the world high CFRDs. It is hereby to formulate this draft for High Concrete Face Rockfill Dam Design Code. The purpose of this Code is to provide guidance to the word CFRD builders to construct high CFRDs successfully.

The main contents of this code include the basic stipulations and requirements for layouts of high and very high CFRDs and their related outlet and draining structures; detailed zonings of dam body rockfills or gravel materials; property of dam filling materials and filling quality standards; dam body design and calculation; excavation and treatment of dam foundation and bank slopes ; design of concrete plinth, face slab and connecting plate; design of joint water stops for all types of joints such as perimeter joints and vertical joints; construction in stages and raising of built CFRDs and arrangement design of prototype observations, etc.

This guidelines will help to the design and construction of world high CFRDs.

CFRD/D001--2008

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1 Introduction

1.0.1 The guidelines are hereby formulated for the purpose of meeting the requirements of development in the world high CFRD construction and guide the design and construction of the world high or very high CFRDs and to construct them in a safety and applied conditions, economic and reasonable, and with updated CFRD construction technology and guaranteed quality of CFRDs.

1.0.2 This guidelines are mainly applied to the designs and constructions of CFRDs above 150m or lower than 250m in dam height. The designs for CFRDs higher than 250m shall be studied specially; and some suggestions are made for 300m level CFRD design. The dependable design proposal in harmony with local geological conditions can be made out by taking full advantage of tests and analysis methods such as simulation analysis of dam construction and overall process of river filling by using different mathematical model, and by application of geotechnical centrifugal model test, etc

1.0.3 The design of high CFRDs should also meet the regulations of the country where the dam site lies besides meeting that of this guide.

2. Terms and Symbols

2.1 Terms

2.1.1 Concrete face rockfill dam (CFRD)：A general designation of a type of dam body filled with rockfils or gravels compacted in layers, and also with its face slab as a anti-seepage system .A dam body filled mainly with gravels is also called as concrete face gravel dam.

2.1.2 Dam height：A height from constructive foundation face of plinth calculated to crest pavement. That can be calculated from the lowest constructive elevation at dam axis and with an explanatory note.

2.1.3 Rockfill dam body：Filled body at downstream of face slab

2.1.4 Extruded curb：A concrete trapezium wall at upstream side curb of lean concrete over the transition material before the construction of the next layer.

2.1.5 Cushion layer：A direct carrier for extruded curb, transferring evenly water pressure to rockfill dam body and the principal part for control on seepage flow stability

2.1.6 Special cushion zone：Located at downstream side cushion zone of perimeter joint and with the function of filtration for chokers for the perimeter joint and its nearby slab and for reservoir deposits.

2.1.7 Transition zone：Located between cushion zone and main rockfill zone or bank slope and rockfill zone, protecting cushion material and justifying the gradual change transient action between rockfill bodies.

2.1.8 Main rockfill zone：Located in the upstream zone of dam body, a main support carrying water pressure.

2.1.9 Downstream rockfill zone：Located in the downstream zone of dam body, keeping the stability of dam body together with main rockfill zone. The influence of its deformation is indispensable on face slab.

2.1.10 Drainage zone :Located in gravel zone or at upstream side of soft rock main rockfill zone, or strong pervious drainage zone at the bottom part of dam body and divided as vertical and horizontal drainage zone.

2.1.11 stone riprap zone：Located at downstream dam toe, formed by dumped hard rock blocks.

2.1.12 Downstream slope paving：Rubble pitching heaped and laid with block stones to protect downstream slope of dam body.

2.1.13 Upstream blanket :Silt ,fine sand , flyash or any other material covered over face slab and perimeter joints, as additional anti seepage function.

2.1.14 Weighted zone：Debris covered over upstream blanket, keeping stability of upstream blanket zone with a protection function.

2.1.15 Plinth：concrete slab connecting impermeable carrier at base of foundation and face slab

2.1.16 Plinth reference line：Intersecting line of face slab bottom and foundation rock surface of plinth

2.1.17 Concrete face slab：A concrete plate type structure located at upstream face of rockfill dam body, with the function of anti seepage

2.1.18 Parapet：A concrete wave wall located at upstream crest side and connecting to face slab crest.

2.1.19 Perimeter joint：Joint between face slab and plinth or toe wall

2.1.20 Vertical joint：Vertical abutment joint between strips of face slab

2.1.21 Horizontal joint：Joint between face slab and parapet, and horizontal joint for stage construction of face slab

2.1.22 Flexible filler：Flexible material prepared with asphalt, rubber and filler, and for water sealing.

2.1.23 Hard rock：rocks with saturation unconfined compression strength ≥30MPa

2.1.24 Soft rock：rocks with saturation unconfined compression strength < 30MPa

2.2 Symbols

1A——upstream blanket zone

1B——Weighted zone

2A——Cushion zone

2B——Special cushion zone

3A——Transition zone

3B——Main rockfill zone

3C——Downstream rockfill zone

3D——Downstream slope paving

3E——Dumped rock zone (or filter dam heel zone)

3F——Drainage zone

F——Concrete face slab

C —— Extruded curb

P —— Connecting plate "X"line——reference line of plinth

3 Dam Layout and Zoning of CFRD Body

3.1 Dam Layout

3.1.1 Dam axis should be selected based on topographical and geological features around dam site area in favor of layouts of plinth and hydroproject, and combining with construction conditions, etc, and then made selection after comprehensive technical and economic comparison .

3.1.2 A gravel CFRD can be constructed on a dense gravel layer in case no weak interlayer such as fine silt sand or clayey soil, etc influencing the deformation and stability of the dam body in the alluvium on the river bed.

3.1.3 It is best to select a plinth line according to the following requirements:

A Place a foundation base of plinth on a firm ground; a weathered rock foundation can also serves as a plinth foundation after being treated with some engineering measures.

B A favorable topography should be selected for a plinth line, laying it flat and up and down slope as possible; The bank slopes shouldn't be too steep at downstream of the plinth line. The requirements for foundation base is the same as that for plinth.

C A plinth line should keep away from the adverse geological foundation such as fracture development, intense weathered , intercalated clay or karst foundation, leaving a minimum for excavating and treating the plinth foundation.

D A second laying out can be carried out based on specific geographic and geological conditions and adjust the line location of the plinth after excavation of overburden of plinth foundation in the initial stage of construction and also the geological and topographic defect can be treated through engineering measures. The designs of high toe wall and seai should be well done as for the mountain slope (equating with the peripheral joint water seal) when a high toe wall is adopted for treating the slope.

3.1.4 The juncture layout between slab and other structures and design of seal connecting to perimeter joint should be well done when other structures are arranged at abutments.

3.1.5 The grout curtain of the foundation of dam, abutment spillway and other related structures should be connected with one another, forming an integral closed seepage proof curtain. Special attention shall be paid to anti-seepage stability and durability of antiseepage curtain, especially to the quality of shallow deep hole consolidation grouting of the dam foundation and increasing properly lines of grout holes for consolidation grouting based on hydrogeological conditions with the increment of dam height resulting in that the head of Seepage water will be higher and higher in the dam foundation.

3.1.6 The layout and excavation of construction structures of hydro project should be analytical investigated in detail, and a comprehensive comparison carried out on balance cuts and fills so as to offer material source for dam construction as possible.

3.2 Zoning of CFRD Body

3.2.1 The principle for zoning of CFRD body is to use local practicable materials and only the insufficient part of dam filling materials to be excavated from a quarry under the premise of ensuring engineering safety and economy , and meet the requirements of stability, infiltration flow and deformation control. The zoning should be divided based on material source and the requirements such as strength of dam filling material, permeability, compressibility, expedient construction and reasonable economical efficiency and formulate corresponding filling criteria for the dam. The dam body is suitable to divide as extruded curb zone, cushion zone, transition zone, main rockfill zone, downstream rockfill zone, and special cushion zone located at downstream side of perimeter joint; a upstream blanket zone and a weighted zone should be designed at the bottom of slab upstream face from upstream to downstream; an extruded curb on the cushion layer. The main rockfill zone extends on to dam axis downstream and an underwater rockfill zone designed below downstream flood level according to different dam heights, quality and storage of rockfills .

The permeability of dam material for each zone should augment from upstream to downstream and meet hydraulic transient requirement. The dam material is free from this restriction below downstream water level at downstream rockfill zone. The upstream portion of rockfill dam body should be of low compressibility. The deformation difference shouldn't be too big between downstream and upstream portion of the rockfill dam body.

A tipped hard rockfill can be placed at downstream dam heel in case the downstream cofferdam connects to the dam body.

3.2.2 The zones of dam can be fluctuated according to demand in case the dam body is filled with gravel; The gravel materials should be filled in the regions of high stress of upstream and central portion of the dam.

3.2.3 A vertical drainage zone should be designed in the upstream zone of the dam body and connecting to the horizontal drainage zone at the dam bottom so as to drain the possible water seepage out of the dam and keeping the dam body in a dry condition at downstream zone as for the sandy gravels or softrock dam body whose permeability doesn't meet the requirements of free drainage . A field stone prism body can be designed at downstream dam heel if necessary with a role of filtration function.

3.2.4 The horizontal width of cushion layer zone should be determined by dam height, landform, construction technology and economic comparison. It shouldn't be less than 3~6m in case construction is carried with a mechanized construction and can be decreased adequately and the width of transition zone is increased correspondingly when backhoes and loaders are adopted through cooperating spreading manually. A up to down variational width layout may be adopted for the cushion layer zone which should be extended downstream properly along bedrock contact surface. Its extension will be defined according to landform of bank slopes, geological conditions and dam height. A flatness requirement should be put forward as for the upstream bank slope of cushion layer zone. A special cushion layer zone with compacted thin layers should be designed at the downstream side of perimeter joint.

3.2.5 A crest too wide as for extrude curb will lower capacity for deformation adaptability

of the curb. Thereby its maximum crest width shouldn't be greater than 12 cm with a inside slope ratio of 8:1. The upstream slope ratio will be adopted based on the design slope ratio with a layer thickness of 40 cm.

4. Filling Material and Their Criteria

4.1 Filling Material

4.1.1 Borrow investigation should find out its storability , quality and exploitation conditions for all materials; The investigation on constructional materials should be carried out in the excavated area according to the requirements of the borrow when using excavated rock materials from structure area , and a test on indoor physical mechanic property should be carried out.

4.1.2 Indoor tests on rocks should mainly include specific density, density, percent sorption, compressive strength and elastic modulus, etc. The chemical analysis should be made on mineral composition and ores should be done.

zone based on test results and engineering analogy.

The indoor tests on dam filling materials should include gradation, porosity, shear strength and compressive modulus, etc. A permeability test and filtration erosion test should also be done for cushion layers, sandy gravels and softrock materials. Stress and strain parameters tests should be also done .

The characteristic index of physical mechanics should be defined reasonably for each subzones based on test results and combining with engineering analogies.

4.1.3 Borrow planning and filling planning should be made out for rock materials (or sandy gravels) and rock materials in the structure area based on the layout of water control projects and the requirements of dam filling material sources and their quality and to arrange them in detail in the construction design.

4.1.4 A medium hardness rockfills (wet compressive strength > 40MPa) or sandy gravel material should be used for the downstream portion of main rockfill zone. The rockmass strength can be properly decreased based on the raise of filling elevation by inches. The scope of main rockfill zone should be extended as possible. The shed line between the main rockfill zone and downstream rockfill zone inclines to downstream of dam axis by not less than 1 : 0.2. The downstream rockfill zone should be also roller compacted to a higher density, making the difference value of modulus between them to minimum. The excavated rock materials from water control project should be used for upper dry zone of downstream secondary zone or lower stress zone , of which is suitable for quality requirements of main rockfill zone or downstream rockfill zone may be also used for the lower portion of main rockfill zone or downstream rockfill zone

4.1.5 A hard rock material should drain freely with a higher compacted density and deformation modulus after being compacted. The maximum size of the dam material shouldn't exceed the thickness of compacted layer, the content of particles < 5mm shouldn't exceed 20%

and that < 0.075mm shouldn't exceed 5%.

4.1.6 The rockfill materials of soft rocks should have lower compressibility and a certain compressive strength and may use for a dried zone above downstream water level at downstream rockfill zone. A special justification and design should be carried out if they are used in the main rockfill zone. A drainage measures can be designed in the dam in case permeability can not meet requirements. Dam slopes and water seal structure of the perimeter joint should be suitable for rockfill material property of soft rocks.

4.1.7 The sandy gravel materials will have a higher shear strength and lower compressibility after compaction suitable for filling a main rockfill zone. The design of seepage flow control should be made for the dam body according to the regulations of Article 5.5 in this guide. .

4.1.8 The portion below downstream water level at dam bottom of downstream rockfill zone should be filled with rocks with free drainage and strong weatherproof capacities; The portion above downstream water level at that zone may use the same materials with that of the main rockfill zone. However the compacting criteria can be suitably cut down , or use of lower quality rocks such as all kinds of soft rock materials or weathered stones, etc.

4.1.9 A fine rockfill material specially produced, screened natural sandy gravel or tunnel excavated ballast may be used for the transition zone. The fines particles of the maximum size of 80 ~ 100mm are required continuous gradation.They should have low compressibility and high shear strength and free drainability after compaction.. The content less than 5mm particles should be 35 ~ 55% and that less than 0.075mm particles should be lower than 2 ~ 10%.

4.1.10 The cushion material should have continuous gradation with the fines content of 40% ~ 55%, a maximum size of 80 ~ 100mm, the content of size < 5mm of 30% ~ 50%,that of size < 0.075mm of less than 8%. It should have internal percolation stability, low compressibility, high shear strength and good workability after compaction.

4.1.11 The sandy gravels selected by sifting, artificial aggregates or the other admixtures can be used for cushion materials. The artificial aggregates should be processed by sound mother rocks with strong weatherproof capacities.

4.1.12 The special cushion layer at downstream side of perimeter joint should be filled with a maximum size less than 40mm , and with a fine filter material of internal stability. It should be compacted in thin layer to consolidation and reducing deformation of perimeter joint as possible, meanwhile placing silt or flyash on the top of joint as a filtering layer.

4.1.13 The upstream blanket zone (1A) of concrete slab should be placed with muddy soil, silt, flyash or other low cohesive materials.

4.1.14 Ballast aggregates can be applied for upstream weighted zone(1B) .

4.1.15 The downstream slope protection is built by laying block stones or placing oversized block stones with bid ends outwards, selected from the rockfill body and conveyed to downstream ramp slope.

4.1.16 Weather-proof rocks or gravels and with good drainability should be selected for

vertical and horizontal drainage bodies if they are designed in the dam body.

4.1.17 The extruded curb provides a stable and reliable supporting plane, ensuring which is a even thickness of slab, reducing construction sequence and keeping the slab from rain impact erosion or wave scour, which is a low strength and semipervious trapezium concrete guard wall.

4.1.18 The concrete compactness of extruded curb should meet the requirements for percolation , strength and elastic modulus and easy to construction, i.e. designing in a mix ratio of first order gradation dry concrete with slump of 0, scale of intensity of C3~C5 and ;permeability coefficient ofl×10-4cm/s.

4.2 Filling Criteria

4.2.1 The filling criteria for filling materials for cushion zone, transition zone, main rockfill zone, and downstream rockfill zone should be integratively defined based on some factors such as grade , height, valley form of the dam, and seismic intensity and borrow features and referring to the same type of engineering experiences

The roller compaction parameters for filling are defined based on compaction function of compacting plants through compaction tests. Equipments with stronger compaction function should are adopted as possible so as to increase filling density, reducing deformation.

4.2.2 The filling criteria for each subzone material can be tentatively defined based on experiences. Their values can be selected within the range of Table 4.2.2. Meanwhile the porosity (or relative density), range of gradation of dam materials and compacting parameters should be defined in the design. The design dry density can be conversed from porosity and rock density. The mean dry density shouldn't be less than the dry density value conversed from design porosity (or relative density), Its standard deviation shouldn't be bigger than 0.1g / cm^3.The porosities of main and secondary rockfill zones are of substantial agreement. The filling criteria for the special cushion zone should be increased at downstream side of perimeter joint so as to reduce deformation of perimeter joint. The design index , filling criteria and portion for soft rockfill materials should be defined through tests and engineering analogy.

Table 4.2.2 Filling criteria for dam materials

aterial or zone	Porosity (%)	Relative density
Cushion material	15 ~ 18	
Transition zone	18 ~ 20	
Main rockfill zone	19 ~ 21	

Downstream rockfill zone	< 22	
Gravel material zone		0.80 ~ 0.85

4.2.3 Watering requirements should be defined for the dam material filling. The water addition can be determined by experiences or tests. Some measures should be adopted to reach the design requirements for the dam without water addition in the course of roller compaction in winter seasons in a severe cold region.

5 Design of CFRD Body

5.1 Crest Structure

5.1.1 The crest width should be defined according to the requirements of operation , layout of crest facilities and construction, adopting 5 ~ 8m according to different dam height. The crest width should also be selected according to pertinent regulations of a country where the dam lies in case a traffic request exists on the dam crest.------

5.1.2 A parapet wall should be placed at upstream side of crest. Its height can be 4~6m, the parapet crest towers 1~1.5m above dam crest. The bottom elevation of parapet should be higher than normal storage water level. The joint with face slab should be designed in detail. A U-type groove structure may be adopted , effectively reducing filling volume of the dam body.
om of the parapet so as to walk for inspection.

A viaduct of 0.6 ~ 0.8m in width should be designed so as to travel for inspection at bottom portion of parapet.

5.1.3 The parapet ought to be indurate and watertight and by checking computation in stability and strength. It should be designed with expansion joints; its waterstop should be connected to that between face slab and the parapet and the expansion joint should offset apart from the joint of face slab.

5.1.4 A settlement reservation freeboard of a dam crest should be set. Its value can be defined by computation or reference to similar projects.

5.1.5 The dam body over the bottom elevation at parapet crest should be placed with fine rockfill materials and lay a pavement. The crest pavement should be designed according to the highway criteria of a country where the dam site lies. A good drainage system should be well designed at dam crest in case a dam crest road exists.

5.1.6 A dam crest structure should be economic and practical, and attractive and durable in architectural treatment, and with well designed lighting facilities .

5.2 Dam Slope

5.2.1 The up and downstream dam slopes can be 1:1.3 ~ 1:1.4 and selected based on physical circumstances. The slopes of soft rock rockfill body should be properly eased. The up and downstream dam slopes can be 1:1.5 ~ 1:1.6 in case a dam is filled with good quality natural gravel materials.

5.2.2 The actual dam slopes between roads may be slightly steeper than the slope value stipulated in Article 5.2.1 of this code, but the average dam slopes should meet the above-mentioned requirements if no roads on the downstream dam slope.

5.3 Stability Analysis

5.3.1 A stability analysis should be carried out on a dam slope of a high or very high CFRD in view of the extreme condition possibly occurred. The corresponding stability analysis and corresponding analytical justification should be carried out when one of the following cases exist.

A weak interbed or fine sand bed, siltage , or cohesive soil interlayer exists in the sandy gravel layer in the dam foundation;

B a dam site located at seismic design intensity, 8°~ 9;

C a rockfill body is overflowed by flood or the rockfill dam body passes a flood season with a cushion layer during construction period , and the depth of retaining water is deeper;

D a dam body filled with soft rockfill materials ;

E adverse terrain conditions .

5.3.2. The shear strength of dam materials should be determined by triaxial compression apparatus.

The material for analogy tests should show the mechanical property of dam materials; the testing conditions should simulate the actual operation conditions.

The shear strength of open grain materials and normal stress has a nonlinear relation; such feature should be taken account for as calculation.

5.3.3 The stability calculation of rockfill dam body should follow the regulations of a country where the dam site lies .The downstream slope should be protected by mesh reinforcement or another economic and practicable protection measure during construction .

5.3.4 The stability calculation against earthquake should be carried out according to the regulations of a country where the dam site is.

5.4 Stress and Deformation Analysis

5.4.1 Different mathematical models should be adopted to analytical study stress deformation at dam body of very high CFRDs; The overall process of simulation calculation should be carried out on construction and impoundment of CFRDs so as to study their deformation rule and disclose the influence law of stress and deformation of large deformation and rheology factors on concrete

face slab and perimeter joint of the dam body through research on issues such as special border simulation (vertical and perimeter joint between straps, interface between face slab and cushion layer, etc) of the face slab and the rockfill creep, etc.

The parameters calculated by finite element method should be defined through testing and combining with similar engineering analysis The simulating materials, sampling conditions and load modes for the tests should reflect mechanical properties of the dam materials.

5.4.2 The mechanical properties of the discontinuous interface of the dam body should be reflected and simulating multi-stage load conditions for the dam body based on filling in stage and impoundment process in the finite element analysis on stress and deformation .

5.4.3 A dynamic analysis should be carried out on the dam body with finite element method so as to make a synthetic judgment on their anti-seismic safety as for the high dams in a seismic design intensity of 8°~ 9° and /or liquefiable soil exists in the foundation. A dynamic test should be done for such dams.

5.4.4 The rationality of computing results should be studied based on construction quality inspection data and prototype observation data from dam body , and analysis in time in order to check and revise computation schema and parameters, and revise the design when necessary.

5.5 Seepage Flow Control on Dam Body

5.5.1 The seepage status , stress deformation and monolithic stability within the dam body should be researched under a extreme case (both failures of perimeter joint and anti seepage system).------ An overall evaluation is made on seepage flow stability of dam body and monolithic stability against sliding based on computing results and presenting the corresponding engineering measures to improve and increase stability and safety of a CFRD.

The cushion materials for CFRDs should be continuous gradation and internal seepage stability, and meet the regulations in Article 4.1.10 and Article 4.1.11 of this code. The coefficients of percolation after compaction should be 1×10^{-4} cm/s.

5.5.2 The drainability in the drainage zone should be ensured to discharge all the water seepage freely out of the dam in case the dam body is mainly filled with sandy gravels and arranged vertical and horizontal drainage zones. The crest elevation at vertical drainage zone should be higher than normal reservoir level; the hydraulic transient requirements should be met between drainage zone and dam body; A filter layer may be designed when necessary.

5.5.3 A seepage calculation should be made and recheck the seepage stability for a rockfill dam body to retain flood temporarily by the cushion materials during a high water season. The seepage calculation can be made referring to the calculation method of a country where the dam site is.

5.6 Earthquake Resistant Measures for Dam Body in Seismic Area

5.6.1 The dam crest should be widened, and flatten the dam slope with a gentle gradient at upper

portion but a steep gradient at lower portion of the dam slope and bermes are designed at variable slopes as for the design intensity of earthquake of 8°~ 9°. The crest of downstream slope face should be reinforced by dry laid block stones, or by reinforced rockfills and the surface strengthened by mesh reinforcement (geogrid) and reinforced concrete grid. A lower parapet wall should be adopted and measures taken to increase the stability of the wall.

5.6.2 The surge height of earthquake should be included when defining the free board of the dam in the earthquake area. The free board should be taken into account to the additional settlement under the action of earthquake on dam and dam foundation when the

earthquake design intensity of 8°~ 9°.

5.6.3 The width of cushion zone should be increased and strengthening its join with foundation and bank slopes . A contact length should be extended properly between cushion material and bedrock and a finer cushion material is used in case the bank slopes are steeper.

5.6.4 Several vertical joints should be selected at a middle portion of face slab and enlarging the gabs between slab joints of face slab , into which, fill compressible high molecular material or other infill plates with a certain elasticity

5.6.5 The reinforcement ratio should be increased at face slab of upper portion on the middle of river valley ------- .

5.6.6 The compacted density should be increased for rockfill material of the dam body , especially where breaks exist.

5.6.7 The drainage ability should be increased in discharge zone in case a dam body is filled with a sandy gravel material. The rockfill should be filled in a certain zone within downstream dam slope.

6 Treatment on Dam Foundation

6.1 Excavation of Dam Foundation and Bank Slopes

6.1.1 The cut surface of dam foundation should try to be of easement, obviating risks of potential structural cracks .

6.1.2 The cut surface of plinth should try to be of easement, obviating escarps and adverse slopes and cutting slopes and leveling by backfill concrete if necessary .

6.1.3 The foundation base of plinth should be excavated to upper portion of weakly weathered layer. A special justification should be made in case the foundation base can be only on weathered and broken or incompetent bed because of restriction of topographical and geological conditions and corresponding reinforced measures should be taken.

6.1.4 The excavation criterion differs with location for rock foundation of dam body. A rockfill body can be placed on weathered rocks unless the deformation modulus is adaptable. The bases for cushion layer and transition material is the same as that for plinth. The foundation of the dam body should be of low compressibility in the range of about 0.3 ~ 0.5 times of the dam height at downstream plinth. The compressibility for the foundation of dam body out of the range of 0.5

times of dam height may be widened.

6.1.5 The thick gravel alluvium should be remained as possible as foundation of dam body; but defined after testing and justification through detail investigation.

6.1.6 The rocky bank slopes above the plinth should be excavated as stable slope or that after being treated so as to safety during its operation period.

6.1.7 The bank slopes should be excavated into a 1:0.5 slope within the range of 0.3 ~ 0.5 times of dam height of plinth downstream at foundation of rockfill body. A stable slope gradient less than 1:0.25 can be excavated in case the bank slopes are very steep, but a low compressive rockfill zone or patched slope by backfilling concrete should be designed. The escarps and overhanging structures obstructing the rockfill body to be compacted should be cleared away. The bank slopes at dam axis downstream should be defined according to the requirements of meeting its self stability

6.2 Dam Foundation Treatment

6.2.1 The dam foundation treatment should get to lessen foundation deformation, increase compressive strength , prevent seepage and erosion on foundation material, and improve flatness on foundation surface so as to meet the requirements of normal and safety performance.

6.2.2 The rock foundation of plinth should be treated by consolidation and curtain groutings.

6.2.3 The consolidation grouting should be in 2 ~ 4 lines and the range of grouting depth is 6~20m.

6.2.4 The curtain grouting should be arranged in the middle portion of plinth and can be combined with consolidation grouting. The curtain should be in 1~3 lines with seepage ratio of 1 ~ 5lu. The depth of curtain may be 5m below relative impermeable bed; also can be selected at a dam height of 1/3 ~ 1/2 based on geological conditions. The layout, depth, and the extended length towards both banks should be defined by calculation and combining the similar engineering experiences under the complicated hydrogeological conditions or a deeper imbedded depth for a relative impermeable bed.

6.2.5 The parameters such as rising extent of grouting pressure , grout proportion and grout acceptance should be defined by testing. The measures should be worked out in the grouting design for increasing durability of grout curtain and grouting pressure of surface bedrock.

6.2.6 The bedrocks within the range of plinth should be treated carefully one by one based on their occurrence , size and constructional material if unfavorable geological conditions exist such as fault, fractured zone and weak interbed , etc , and by replacement treatment with concrete plugs , extending to a certain distance towards to downstream, and by covering them with filter material and reinforcing the grouting into plinth.

6.2.7 The karst development status should be found out in case plinth lies in a karst foundation and a special justification should be carried out on their anti seepage treatment measures.

6.2.8 The plinth foundation can be treated with following measures in case it is on a deep weathered fractured and weak rock formation so as not be excavated to a moderated weathered

stratum:

A. extending seepage path such as widening plinth, designing downstream anti seepage plate and concrete cut-off wall ,etc

B. adding expansion joints

C. covering filter material over the downstream

7 Concrete Plinth

7. 0 1 The following 3 modes for selection of plinth layout:

A. The contour line of plinth surface perpendicular to its line of reference;

B. The contour line of plinth surface perpendicular to dam axis;

C. The contour line of plinth surface meeting the requirements of excavated rock face

The Scheme A is called as flat plinth. The flat plinth is easy to construct and considered firstly to adopt.

7.0.2 Rrequisite expansion joints should be designed based on topographical and geological conditions for the plinth on bedrock and staggered arrangement to the vertical joints at face slab; The construction joints at plinth can be designed based on construction conditions; The outer corner of plinth takes the form of junction block as its body type.

7.0.3 The allowable hydraulic gradient of the rock foundation underneath the plinth should be

Table 7.0.3 allowable hydraulic gradient of rock foundation

Rock rot degree	allowable hydraulic gradient	Rock rot degree	allowable hydraulic gradient
Fresh,weak weathering	≥20	Intense weathering	5 ~ 10
Moderate weathering	10 ~ 20	Full weathering	3 ~ 5

7.0.4 The plinth width on rock foundation is defined according to allowable hydraulic gradient. The plinth should be adopted with different width according to head in elevation section. A minimum width of a plinth shouldn't be less than 3m ;

An additional downstream anti seepage plate can also meet the requirements of hydraulic gradient for plinth; still the width of plinth should meet the requirements of grouting. The surface and the downstream of a downstream anti seepage plate should be covered with filter materials.

7.0.5 The thickness of plinth on rock foundation may be less than that of face slab connecting to it ; A minimum design thickness shouldn't be less than 0.3m; that of bottom plinth shouldn't be less than 0.5m and a different thickness may be adopted according to its elevation in sections.

7.0.6 The height of the plinth downstream surface normal to the basal plane of face slab shouldn't be less than 0.9m with a slipform construction.

7.0.7 The plinth foundation overexcavated over 1m should be filled and leveled up with concrete firstly before placing the plinth.

7.0.8 The plinth should be defined based on the terrain condition and will have a length of repose not less than 0.6m so as for railless slipforming for face slab in case the face slab and the plinth are in the same plane.

7.0.9 The concrete property and its requirements of crack control for plinth are the same as that of face slab, referring to the regulations in Articles 8.3 and 8.5 of this Code.

7.0.10 The steel ratio in each way for reinforcing bar of plinth on bedrock can be 0.3% ~ 0.4% of design thickness of flat plate section ; The bar arrangement should be in single layer and double way with a protective covering thickness of 10 ~ 15cm.

7.0.11 The plinth should be joined to the bedrock with grouted bolts. The parameters for the bolts can be defined according to experiences and should be defined by stability and resistance to grouting pressure in case low dip angle structural plane around base level of plinth.

7.0.12 Generally, no stability analysis is needed for plinth. The stability and stress analysis are needed if the thickness of plinth exceeds 2m. The method of limit equilibrium for rigid body is applied for the stability analysis for plinth. The anchor bar effect and the transport power between face slab and plinth won't be accounted for in the calculation. The rockfill pressure can only take into account of active pressure of the rockfill or of lateral pressure generated by rockfills under face slab after carrying reservoir pressure.

8 Concrete Face Slab

8.1 Parting and Partitioning of Face Slab

8.1.1 The parting and partitioning of face slab should be done based on deformation of dam body and construction conditions. The space between vertical joints can be 12 ~ 18m . A permanent horizontal joint is designed at 1/3 dam height of upper portion of face slab as the case may be for above 200 m high CFRDs according to the actual conditions .

8.1.2 The tensile vertical joints should be designed for the face slab near both the abutments, and for the other parts of face slab compressive vertical joints are designed. The Number .of tensile vertical joints are defined based on topographical and geological conditions and referring engineering experiences or finite element calculation.

8.1.3 The arrangement of construction joints at face slab should meet the requirement of temporary water retaining or water storage in phases. The joint surface of concrete construction joint should be green cutted, cleaned clearly, the joint surface wetted with water, and placing a thin layer of high strength mortar before going on placing concrete. Face slab steel bars should go though joints. The horizontal construction joint of slab should be parallel with its normal direction. The thickness in normal direction shouldn't be less than 1/2 slab thickness at least

8.1.4 The construction joints at face slab placed in stage should be lower than the crest elevation at the filling body and the height difference should be higher than 5m. The face slab concrete should be additionally placed after impregnating densely with low grade and low compressive mortar in case any cavity is found between placed face slab and cushion layer so as to ensure them well bonded

8.2 Face Slab Thickness

8.2.1 The definition of face slab thickness should meet the following requirements:

A. Facility to installation of steel reinforcement and water stops within it. The minimum thickness is 0.30m.

B. Controlling percolation hydraulic gradient doesn't exceed 200;

C. A thinner thickness of face slab should be selected for increasing flexibility of face slab and decreasing its construction cost with the premise of meeting the above requirements.

8.2.2 The thickness at corresponding height of face slab can be defined according to the following computation expressions:

$$T = 0.30 + 0.0035H \quad (m)$$

Where, T = Thickness in meters;
H = Height in meters.

8.2.3 The minimum thickness of face slab can increase to 40cm, $T = 0.40 + 0.0035H$ (m) for the easy extruded failure zone of central face slab on the valley section with respect to the high CFRD in a narrow valley.

8.3 Face Slab Concrete

8.3.1 Face slab concrete should be of food workability, crack resistance, impermeability and durability. The corresponding indexes are as follows:

The level of face slab concrete strength shouldn't less than C25;

The grade of concrete frost resistance should be defined according to the regulations of a country where the dam lies.

8.3.2 A composite Portland cement or ordinary Portland cement should be used for the face slab concrete. A comparative test should be carried out for defining type of concrete in case adopting another variety or strength grade of cement.

8.3.3 The flyash or other quality admixtures should be mixed in the concrete of face slab. The degree of flyash fineness shouldn't be bigger than 45 μm, the content of flyash should be 15% ~ 30% ,or define based on relative regulations of a country where the dam lies.

8.3.4 A proper amount of flyash can be admixed in case poor aggregate gradation and coarser sand material for improving concrete workability; Substitution of flyash may be possible to reduce cement and sand material so as to improve concrete performance.

8.3.5 The concrete of face slab should be admixed with air entraining agent, simultaneously with highly active or common water reducing agent . Other type of additives may be also added to adjust the set time of concrete according to the requirements. The type and content of admixtures or additives should be defined by testing.

8.3.6 A Gradation II aggregates should be adopted for face slab concrete with a maximum size not bigger than 40mm. The percent sorption of sand materials for face slab should not bigger than 3.0%, the silt content not bigger than 2.0%, and fineness modulus within 2.4～2.8. The percent sorption of stone materials for face slab should not bigger than 2.0% and silt content not bigger than 1.0%.

8.3.7 Water cement ratio of concrete of face slab should be less than 0.50 in temperate area, and less than 0.45 in cold or severe cold area. The slump should meet the construction requirement , the slump at access point of chute should be controlled by 3～7cm in case concrete is conveyed with a chutting system . The air content of concrete should be controlled at 4%～6%.

8.4 Steel Reinforcement Installation

8.4.1 A single layer and two way steel reinforcement should be installed on the centre portion of the face slab cross section with ratio of 0.3%～0.4% each way and the ratio in horizontal direction may be less than that in vertical direction.

8.4.2 A reinforced steel bar may be properly deployed at strong tensile stress zone or perimeter joint at both banks and its vicinity. A resisting extruding constructional reinforcement should be placed at both sides of vertical joints close to perimeter joint, but such placement of reinforcement shouldn't influence installation of waterstops and the quality of vibrated concrete nearby the waterstops.

8.4.3 The double-layertwo-way reinforcement should be designed as for the compression steel in the face slab on the middle portion of a narrow valley

8.4.4 The area of reinforcement should be calculated based on the design thickness of face slab concrete.

8.5 Anti-cracking Measures for Face Slab

8.5.1 The base surface of face slab and the foundation of both abutments should be flat without oversize waviness , local kolks nor cusps. The side forms should be straight.

8.5.2 The 28d compressive strength should be about 5MPa in case stabilizing the slope of cushion material with roller compacted mortar or shotcreting so as to reduce constraint on the base surface of face slab.

8.5.2 Additives and admixtures should be adopted in the mix ratio for face slab concrete so as to reduce cement content and water consumption and lessen temperature rise due to hydration

heat ,and shrinkage strain. An aggregate of low thermal expansion coefficient should be selected according to actual conditions of the project so as for the slab concrete to have a higher tensile strength and ultimate tensile value.

8.5.3 The concrete of face slab should be placed in a low temperature season and control the placing temperature , and strengthening damp-preservation curing and insured curing on the surface of concrete face slab ,and stop curing until water impoundment or 90d at least.

8.5.4 The parapet concrete should be then placed with as the settling volume can be controlled within 5 ~ 6mm/m after the concrete of face slab is placed up to crest.

8.5.5 A special measure should be adopted to treat the cracks when they are wider than 0.2mm or defined as permeable cracks. The strict treating standard should be defined for the cracks at face slab of CFRDs in severe cold region or pumped storage stations. One layer of anti-seepage, insulation and anticrack paint sprayed or coated on face slab can prevent temperature cracking at face slabs.

9 Joint Seal

9.1 Installation of Joint Waterstops

9.1.1 A waterstop should be installed in the perimeter joints. The bottom copper waterstops should be installed as the basic anti seepage line, the medium PVC or rubber waterstops and waterstops at upper portion should be selected according to actual conditions. The upper sealing system is generally made up of flexible filler, fine silts (or flyash), etc, may be one type of sealing material , and also a flexible filler and cohesionless material. Bottom and upper waterstops or bottom, middle and upper waterstops should be adopted for high or very high CFRDs, depending on actual conditions. The seal structure of perimeter joint in a macroseismic area should be defined based on the findings of related dynamic calculation and joint tests. The thickness of bituminizing joint board should be determined based on the findings of related dynamic calculation and joint tests in view of a greater deformation of the perimeter joint in a macroseismic area.

9.1.2 The compressive vertical joints should be changed into construction joints. The steel reinforcement should go through joints in the face slab and cancel waterstops and a hard flat joint structure should be adopted; one bottom waterstop is needed for all these cases. . An anti-seize compound should be coated at one side face of joint such as asphalt emulsion, etc. and the hard flat joint is additionally packed with bituminous wood plate. PVC pads should be placed and bonded the cement mortar pad under the copper waterstops. The base angles at both sides of copper waterstops should be placed with bitumen stop-grouting strap.

The vertical web height of copper waterstop is about 3 cm. the strap doesn't account for the thickness of face slab. Reduce depth of the V- notch or not use V notch.

9.1.3 The vertical tension joints should be adopted with bottom and / or upper waterstops and the structures are the same of compression joints.

9.1.4 The steel reinforcement should go through the horizontal construction joints at face slab without installation of waterstops .

9.1.5 A copper waterstop, PVC waterstop or rubber waterstop can be adopted for expansion joints at plinth., forming a closed system with the parimeter joint waterstops.

9.1.6 The horizontal joint between parapet wall and face slab. should be designed with bottom and top waterstops

9.1.7 The middle and top waterstops should be joined together with the bottom waterstops at the connected joints and forming a closed structure. The PVC waterstops or flexible filler should be connected with bottom waterstops at the vertical joints by holding device. The waterstop face membrane should be felted or welded and fastened into face slab.

9.18 Angle bars should not be used at a water fluctuation section in stage in a cold region. Expansion bolt is used as fixed parts for waterstops, flexible filler face membrane. The fixed parts should be binding materials so as to avoid being ruptured due to frost heaving, bereaving its fixation.

9.1.9 The joint seal between concrete cut-off wall and connecting plate should be designed according to that of perimeter joint watertops.

10. Stage Construction

10.1 Construction in Stage

10.1.1 Stage construction plans should be reasonably worked out for dam body filling and fce slab placement based on the requirements such as topography at dam site, construction progress, diversion and safety in the high water season, reservoir filling, etc. The presettling time should be 5~7 months for the rockfill body underneath the face slab and the settling value shouldn't be greater than 5 ~ 6 mm in the converging month during the presettling period.

The construction of modern CFRDs require equilibrium rise of upstream and downstream rockfill body. The backfilling level of the downstream rockfill material is slightly higher than that of the upstream rockfill material so as to eliminate the influence of differential deformation on face slab behavior, which results from differences of modulus and time between upstream and downstream rockfills except for the requirement that the rockfill should be filled to the flood retention elevation within the first low water period.

10.1.2 The stage filling planning for rockfill dambody should keep to the follow principles.

A Cushion and transition materials should be filled levelly with adjacent part of rockfill materials.

B The binding slope gradient between rockfill materials shouldn't be steeper than 1:1.3, and that between natural sandy gravel materials not steeper than 1:1.5.

C Temporary ramp roads can be designed for transporting dam filling materials in the rockfill zone.

D The filling zones should be in accordance with requirements of safety of high water season when retaining water with a temporary cross section or flood passing cross the dam in a high water season.

E The binding site should be treated as filling the next cross sections , avoiding block stones

to be centralized; Clean out noncohesive materials on sections properly and strengthening roller compaction on binding sites.

10.1.3 The requirements of anti-sliding stability and seepage stability should be met in case temporary section of dam body is used to retain flood in a high water season.

10.1.4 The waterway surface , downstream slope surface and toe of slope all should be protected appropriately when flood passes through the dam body surface so as to avoid erosion by currents in a high water season during construction period .

The means for protection should be determined based on the physical circumstances such as waterway surface type and flow speed, protected materials, etc. A hydraulic model test should be carried out for the important projects so as to offer the reference for selection of protective measures

10.1.5 The horizontal joint is treated according to construction joint as the concrete face slab is placed in stages and following the stipulates in Article 8.1.3 of the guide.

10.1.6 The CFRD built in stages should be reached to the design specification for the finalized size. The plinth, slab, seal , parting and dam foundation treatment of the first stage works should be constructed according to final planned section. No parapet is designed for the first phase works.

11 Safety Monitoring

11.0.1 The safety monitoring should be defined according to the relative regulations of a country where the dam site lies for high CFRDs. Some necessary observation instruments should be placed following the principle as “few but best ” based on grade , height, structural type of a dam, and topographical and geological conditions; a systematic observation to be carried out during construction and performance periods , and taking order with analytic data in time.

11.0.2 The following observation items designed for high CFRDs:

A vertical and horizontal displacement at dam face
B vertical displacement within dm body
C joint displacement
D deformation and strain at face slab
E seepage flow
F horizontal displacement within dam body
G settlement at alluvium of dam foundation
H seepage pressure on foundation and body of dam and roundabout seepage at abutments
I Thrust of ice cover on face slab in a cold region
J crack monitoring on concrete face slab
K earth and contact pressures
L monitoring on concrete cut-off wall
M monitoring on toe wall or retaining wall
N Monitoring on separation of face slab
O. Seismic response

11.0.3 The design of safety monitoring should be meet requirements of observations during construction period and obtain the early observation data so as to guide construction and

optimize design.

11.0.4 The selection of observation instruments should be in line with the principles as reliability, durability, economy and practicality and try for update instruments; Realizing observation automation if condition allowance.

The observation instruments should be arranged according to the following principles such as,

A capable for reflecting service behavior of the dam all roundly

B outer surface deformation observation points can be generally installed in an equidistance

C internal observation instruments should be installed at least along a cross section at a maximum dam height. Additional observation sections can be arranged along longitudinal profile of dam axis, not less than 3 observed profiles at least in necessary.

D internal observation instruments should avoid construction disturbance as possible and convenient for observation activities, and ensure possibility for observation on necessary items under the condition of an atrocious weather

E strengthening observation items such as deformation of concrete face slab, three way deflection at perimeter joint and seepage rate , etc. The seepage rate observation should try to distinguish the seepage rates from the both banks or dam foundation so as to estimate exactly the status of seepages from dam foundation and both banks , and performance of dam and its foundation.

12 Design Proposals for 300m CFRDs

12.0. 1 Zoning of 300m CFRDs

Higher requirements of both stress transition and seepage flow transition are needed for 300m CFRDs. So, The main materials are divided into 11 zones for CFRD body (See Fig.1).

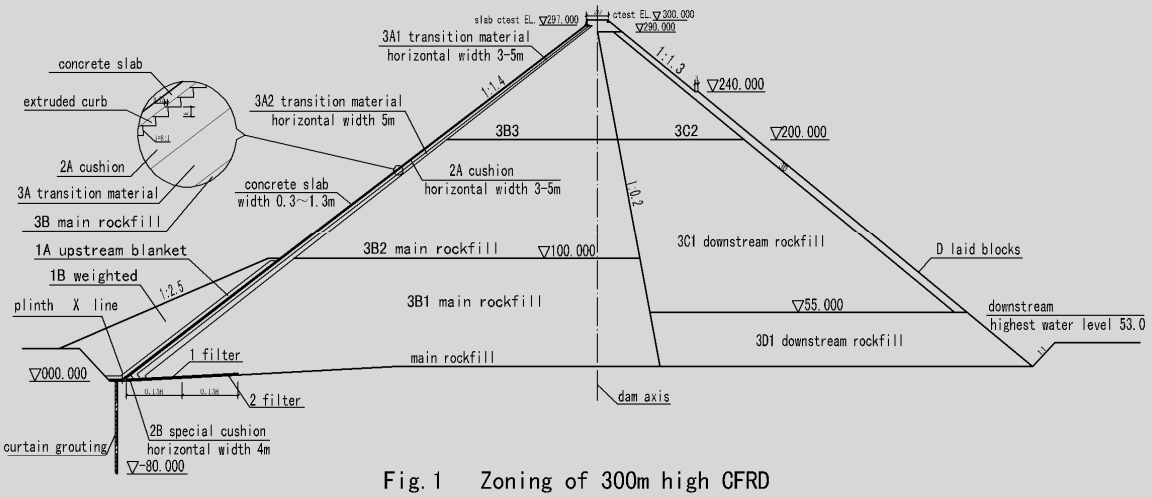

Fig.1 Zoning of 300m high CFRD

2A1—cushion material zone, horizontal width of 3~6m , underneath face slab and narrow according to lineation based on acting head.

2A2— mini zone material, lies at perimeter joint of cushion material portion, bottom width of 4 m, slope of 1：1.4 towards downstream

3A1—filter transition material zone , horizontal width of 3~6m , 3 layers divided by the principle in height difference of about 100m of main rockfill material so as to make the most of using dam filling material with different property; 100 m at the lower portion,main rockfill material Zone I

3B1— 100 m at the middle portion , main rockfill Zone II

3B2— 100m at upper portion , main rockfill Zone III

3B3— downstream rockfill zone, divided into 4 subzones , The height difference of division is substantial agreement with the main rockfill zone.

3D1— about 100m at bottom portion, downstream rockfill material Zone I (drainage zone)

3C1— about 100m at middle portion within the dam shell , secondary rockfill material

Zone I

3C2— about 100m at upper portion inside the dam shell, secondary rockfill material

Zone II;

3D2— outside 3C1 and 3C2 Zones, 20m close to dam slope , downstream rockfill material

Zone II

The shed line of upstream main rockfill zone（3B1,3B2,3B3）and downstream rockfill zone

（3D1,3C1,3C2）should incline downstream and the slope gradient shouldn't be steeper than 1：

0.2 in view of the trajectory of principal stress.

The upstream cover material zones shouldn't be 1/3 of the dam height and divided as blanket material Zone I A and weighted material Zone 1B.

Zone 1A is incoherent material and the cushion material should form the filter protection of it

Zone 1B should mainly retain the stability of upstream slope.

12.0.2 A special compacted zone should be added as for steep bank slopes for CFRDs in the narrow river valley. The compactness of this zone is the same as that of transition material so s to decrease adverse effect of side slopes on deformation of dam body.

A filter material zone should be added at portion with special geological conditions.

12.0.3 Select compaction equipments with great power and high performance

12.0.4 Select high performance joint sealing materials suitable for high head and large deformation

12.0.5 Present well targeted antiseismic engineering measures

17.0.6 Select monitoring instruments suitable for monitoring properties of high CFRDs ; define the burying technologies ensuring instruments to be well buried .