Inspection and reliability assessment for Gandjelas concrete gravity dam

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Abstract: Inspection, analysis and reliability theories and methods for Gandjelas gravity dam are introduced in this paper. It is indicated that construction joints are the main cracks in the concrete gravity dam, with the depth of the main cracks being about 600 mm, and the depth of minor cracks being 200 mm. The integrity of the dam is deceased by cracks of upstream face and corridor, and leakage inevitably occurred after water level rising. Integral stability and reliability of the gravity dam is slightly deficient, and the stress distributions of the dam body correspond with “DL5108-1999 Design Specification for Concrete Gravity Dams”. Considering structural safety, function and durability, horizontal construction joints are reqarded as dangerous cracks, which need to be repaired. Pre-stress anchor system and anti-permeation system are proposed to solve the delaminating of construction joints and dam leakage. NBS mortar is introduced on the spillway for repair and maintenance, and grouting permeability reducing admixture is used to repair the horizontal construction joints and cracks on the wall of the corridor.

Key words: defect inspection; reliability assessment; concrete; concrete qravity dam

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安哥拉 Gandjelas 混凝土重力坝安全检测与评价分析

摘　要：介绍了安哥拉 Gandjelas 重力坝的现场调查、检测、试验和理论分析的方法、依据和主要结论。检测表明，原混凝土的水平施工缝张开，层间施工质量难以保证；复核计算表明大坝整体稳定略显不足，坝体应力分布符合 DL5108—1999《混凝土重力坝设计规范》规定。为综合解决整体稳定不足、渗漏和外观缺陷等影响正常运行的问题，建议在大坝上游面采用预应力岩锚加固，上游面裂缝采用灌浆、嵌缝和使用水泥结晶防渗材料处理等综合措施，下游溢流面采用 20 mm 丙乳砂浆修补，廊道内裂缝进行 EA 改性环氧灌浆材料灌浆处理。

关键词：病害检测；安全评估；混凝土；重力坝

0 Introduction

Gandjelas dam is a gravity dam which is situated in Chibia province of Angola, with the reservoir capacity of 3.5×10^6 m^3, maximum height of 30 m, downstream-face slope of 1∶0.70. The dam was built in 1960s and 1980s by two different contractors. In 2005, rehabilitation of the dam was initiated by Sinohydro Corperation of China. Dam defaults such as horizontal construction joints, shrinkage cracks and visual defects are discovered. For safety, function and concrete durability of the dam, it is necessary to inspect the defects of dam concrete. The content of inspection and assessment is listed as follows:

(1) Collecting data of design and construction such as drawings, photos, etc.;

(2) Inspection on site;

(3) Analysis of stress and deformation of the dam;

(4) Dam reliability assessment;

(5) Suggestions for strengthening or repair.

Content of inspection: Concrete strength, visual and bond characterization of construction joints, interior defaults of concrete, cracks’ distribution.

Mathematical model & structural analysis: based on rigid body balance model and elastic-plastic model, assessment of the integral stability, reliability and stress distribution of dam body is carried out, and engineering mechanics and ANSYS (FEM software) are adapted.

Reliability assessment: Deformation with varied

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overload coefficient, and dam reliability is presented.

Suggestions for strengthening and repair: Focusing on the integral stability, reliability and the leakage of dam, pre-stress anchor system and anti-permeation system are suggested.

1 Technical specification & inspection method

1.1 Technical specification

(1) CECS 03:88 Technical Specification for Testing Concrete Strength with Drilled Cores.

(2) JGJ/T 23-2001 Technical Specification for Inspection of Concrete Compressive Strength by Rebound (Sclerometer) Method.

(3) DL5108-1999 Design Specification for Concrete Gravity Dams.

(4) DL/T5057-1996 Code for Hydraulic Concrete Structures.

(5) DL/T5207-2005 Technical Specification for Abrasion & Cavitation Resistance of Concrete in Hydraulic Structures.

(6) DL/T5150-2001 Test Code for Hydraulic Concrete.

(7) GB50204-2002 Code for Acceptance of Constructional Quality of Concrete Structures.

(8) CECS 21:2000 Technical Specification for Testing Concrete Default by Ultra-sonic.

(9) SL230-98 Specification for Maintenance and Repair of Concrete Dam.

1.2 Inspection methods

(1) Concrete compressive strength

Core-drilling method and rebound (sclero-meter) method are adopted for concrete tests in dam faces and corridors.

(2) Internal defects of concrete

Drilling cores method and ultrasonic pulse-echo method are adopted to detect concrete internal defects for 4th structural dam.

(3) Cracks distribution

Cracks distribution is noted through visual inspection by highly experienced engineer, the width is measured by magnifier, while the length and depth with Tapeline and ultra-sonic apparatus respectively.

(4) Carbonation depth

During the hydration of the cement, Ca $(OH)_2$ is formed resulting in the pH-value of the pore water being about 12.6. To prevent corrosion of the steel reinforcement a minimum pH-value of 11.5 is required. The Ca $(OH)_2$ reacts with the carbon-dioxide of the air resulting in a decrease of pH-value, i.e.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

A fracture surface (perpendicular to the external concrete surface) is sprinkled by a liquid indicator, preferably Phenolphthalein.

2 Inspection of dam concrete

Dam concrete defects consist of cracks, delamination, spalling, efflorescence, popouts, wear or abrasion, collision damage, scour, etc. the inspection of concrete should be done by both visual and physical examinations[1-2].

2.1 Visual inspection of concrete

(1) Cracks and construction joints

Fig. 1~5 show cracks and construction joints. Cracks can be classified into two categories, one is horizontal construction joint, and the other is shrinkage crack. Those with 1.0~5.0 mm in width and 1500 mm at interval are main construction joint and crack, formed during the pouring. While those with 0.3~1.0 mm in width and 500 mm at interval are minor construction joints and cracks. Two minor construction joints always appear between two main construction joints.

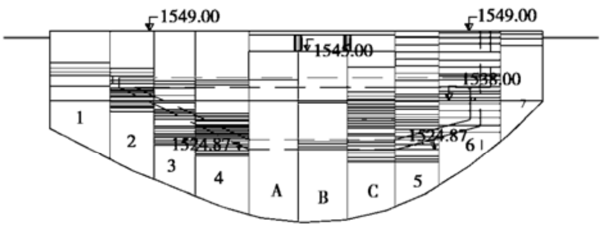

Fig. 1 Detectable construction joints and cracks of dam

Fig. 2 Horizontal construction joints of upstream face

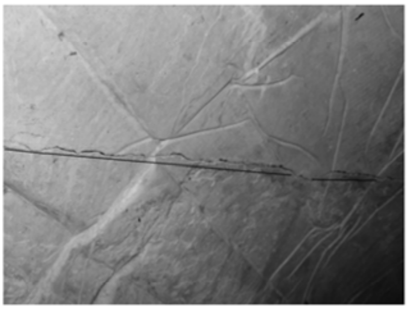

Fig. 3 Horizontal construction joints of corridor

Fig. 4 Horizontal construction joints of upstream face

Fig.5 Circle cracks of top corridor

According to inspection of drilled cores, the depth of construction joints are about 300~ 400 mm, and the width is just the same as that of surface, joints between two layers have bond characterization with yellow crystalline mass attached, although chisel-tooth had been done to construction layers, most surfaces of construction joints are smooth, and biting action of aggregate is small. In general, hairline of main construction joints and cracks disappeared in 600 mm, while that of minor construction joints and cracks is 200 mm.

The cracks width of top corridor is 1~4 mm, the width of vertical cracks is less than 1 mm, relatively smaller than horizontal construction joints and cracks, and perpendicular to horizontal construction joints. The cracks in corridor and vertical cracks are caused by concrete shrinkage.

The deterioration of construction joints is caused by construction technique and by differences between concrete-body strength and construction-joints strength; in general the tensile strength of concrete body is much stronger than that of construction joints. According to construction state of Russian, the height of moulding board is about 1500 mm, and concrete is poured in layers of 500 mm for easy temperature-control inside of the moulding board. Although the time interval of construction both in height of 1500 mm and in height of 500 mm exceeded permanent time of cement hydration, the time interval of pouring in 500 mm is much shorter than that in 1500 mm, the former tensile strength is stronger than that of the latter. As a consequence, width of racks which occurred in concrete pouring with 500mm's height is much smaller than that of 1500 mm.

(2) Spongy surface of concrete

Although most of concrete face is smooth and integral, spongy is covered on concrete surface in some area (see Fig. 6). It is concluded that bad construction quality control during construction is the main reason. The spongy appears near the construction joints where aggregate is easy to be rolled and separated from concrete during pounding. As a consequence, spongy destroyed anti-permeation system.

Fig. 6 Concrete spongy in right side

(3) Separation $CaCO_3$

Separation $CaCO_3$ refers to decomposing of white crystal $CaCO_3$ on external surface from $Ca(OH)_2$ in concrete by means of small quantity of water (see Fig. 7). With development of water leakage, $Ca(OH)_2$ in concrete is deceased to its critic level. As a consequence, the hydration calcium silicate, hydration calcium aluminates, and hydration calcium ferrite are decomposed, when free $Ca(OH)_2$ in concrete is reduced down to 75%, concrete compressive strength is degraded to 50%, while $Ca(OH)_2$ reduced down to 67%, concrete compressive strength should be destroyed completely.

Fig. 7 Separation $CaCO_3$

(4) Scaling and popouts of concrete

Concrete defects such as scaling, palling, efflorescence and popouts are presented in downstream face of spillway, see Fig. 8, so as the diversion holes, see Fig. 9.

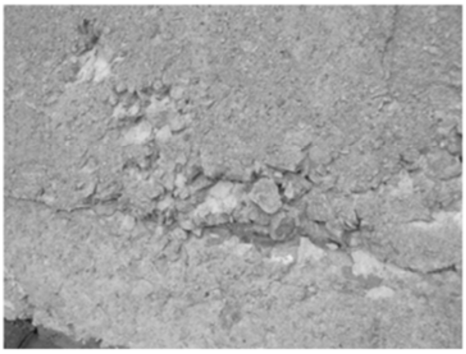

Fig. 8 Defects in the spillway

Fig. 9 Defects in the diversion hole

2.2 Concrete compressive strength

Concrete compressive strength is determined by drillers and non-destructively tests with sclerometer. table 1 shows the strength results by sclerometer tests, and table 2 shows results by drill cores testing. Average of concrete compressive strength is 38.8 MPa, the maximum is 48.8 MPa, and the minimum is 27.0 MPa. Although concrete strength of spillway is larger than C25, concrete deteriorations such as scaling, palling, efflorescence and popouts do not satisfy dam safety, function and durability for ageing.

Table 1 Compressive strength tests with sclerometer

Item	Position	Compressive strength/MPa			
		Group	Max	Min	Average
1	Spillway	8	31.5	19.4	23.2
2	Spillway wall	10	24.9	20.6	23.1
3	Dissipation	8	30.8	21.3	27.7
4	Non-spiillway	11	38.5	18.2	24.9
5	Upstream face	26	47.2	21.3	35.2
6	Corridor	14	47.1	22.0	35.8

Table 2 Compressive strength with drilled cores

Item	Position	Compressive strength/MPa			
1	Right non-spillway	32.7	27.0	42.5	
2	Right spillway	41.4	46.0	40.9	
3	Upstream face	32.7			
4	Bottom corridor	38.6	35.8	40.7	45.1
5	Top corridor	33.4	32.7	33.1	29.6
6	Left non- spillway	32.0	48.8		

2.3 Carbonation depth

Table 3 shows the measured carbonation depth.

Table 3 Carbonation depth of concrete

Item	Position	Carbonation depth/mm			
		Group	Max	Min	Average
1	Spillway	20	25.5	15.5	20.0
2	Spillway wall	10	25.0	14.5	19.5
3	Dissipation	8	26.0	17.5	21.5
4	Non-spillway	11	24.0	16.5	21.0
5	Upstream face	26	27.0	14.5	20.5
6	Corridor	14	24.0	16.5	19.0

2.4 Internal defects of concrete

Drilling cores method and ultrasonic pulse-echo method are adopted to detect concrete internal defects for 4th structural dam, 2 holes (Ø75 mm) located next to upstream 860 mm, which are drilled into dam foundation 1500 mm, either visual inspection of cores or ultrasonic waves can judge the internal defect of concrete.

(1) Drilling cores

Fig. 10 shows drilled cores, it is concluded that the cores are broken by concrete internal defects and construction joints, and the ratio of cores adopt is lower than normal level, the cores of foundation and dam turn into pieces.

(2) Ultra-sonic detection results

Cross-hole sonic logging is performed by apparatus NM-4A (ultrasonic transducer generates and receives), the results of detection are as follows: ① 1949.00~1942.50 m: low velocity, and no first reflected wave; ② 1941.40 m: no first reflected wave, concrete in layers; ③ 1940.00 m, 1939.70 m and 1939.40 m: low velocity wave; ④ 1938.80~1936.60 m: no first reflected wave; ⑤ 1936.30~1934.60 m: low velocity wave; ⑥ 1934.00~1933.70 m: non first reflected waves with inclined detection; ⑦ 1931.00~1929.50 m: low velocity wave; ⑧ 1926.10 m: non first reflected waves with inclined detection; ⑨ 1921.00 m: non first reflected waves with inclined detection.

(a) Cores of 1949.00~1942.00m of 1st hole

(b) Cores of 1942.00~1936.00m of 1st hole

(c) Cores of 1936.00~1930.00m of 1st hole

(d) Cores of 1930.00~1924.00m of 1st hole

Fig. 10 Aspects of drill cores

3 Integral stability analysis

Probability-based partial coefficient limit stated design method is adopted in structure analysis. The dam integral stability, stress of foundation and dam should be computed with the bearing limiting state, while the tensile stress of upstream and downstream face with the normal application limiting state. Fundamental combination limiting state is stated as follows:

$$\gamma_0\psi \cdot S\left(\gamma_G G_K, \gamma_Q Q_K, \alpha_K\right) \le \frac{1}{\gamma_{d1}} R\left(\frac{f_K}{\gamma_m}, \alpha_K\right). \quad (1)$$

Accidental combination in limiting state is stated as follows:

$$\gamma_0\psi \cdot S\left(\gamma_G G_K, \gamma_Q Q_K, A_K, \alpha_K\right) \le \frac{1}{\gamma_{d2}} R\left(\frac{f_K}{\gamma_m}, \alpha_K\right). \quad (2)$$

3.1 Conditions and parameters[3]

(1) Characteristic water level

Fig. 11 shows typical cross-section, according to relative state, characterization water levels are: ① design water level: 1545.00 m; ② design flood water level: 1547.60 m; ③ dead water level: 1530.70 m; ④ sand sediment level: 1521.0 0m; ⑤ downstream water level: 1521.50 m.

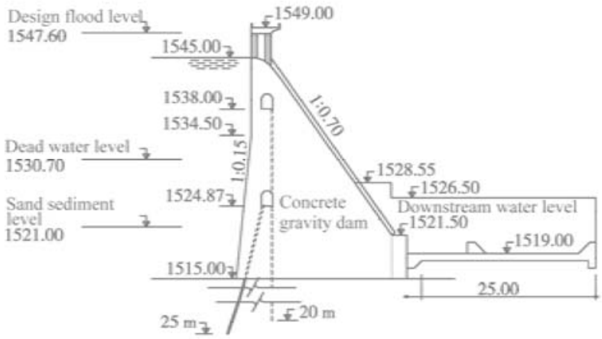

Fig. 11 Typical cross section

(2) Combinations

Table 4 shows water level (load) combinations, the effect of sand sediment loading is considered into all combinations.

Table 4 Load combinations

Item	Load combinations	Water level/m		Flux
		Upstream	Downstream	/($m^3 \cdot s^{-1}$)
1	Fundamental	1545.00	1521.5	0
2	Accidental	1547.60	1521.5	274

(3) Shear parameters of joints

According to SL253-2000 Design Specification for Spillway, Table 5 shows shear parameters of general joints, shear parameters between concrete and rock are shown in Table 6. Considering parameters suggested by specification and inspection, the shear parameters between concrete construction joints, concrete and rock foundation are adopted as f' =0.80, c' =0.25 MPa.

Table 5 Shear parameter of construction joints of concrete

Type	f'	c' /MPa
Joints with adhesive	0.80~0.60	0.25~0.10
Joints without adhesive	0.70~0.45	0.15~0.05

Table 6 Shear parameter of joints for rock foundation

Type	Value of average and normal			
	f'	c'	$m_{f'}$	$m_{c'}$
Joints without adhesive	0.52~0.60	0.41~0.47	0.30~0.38	0.19~0.24
Joints with adhesive	0.60~0.68	0.47~0.53	0.38~0.52	0.24~0.33

(4) Partial and structural coefficient

According to DL5108-1999 Design Specification for Concrete Gravity Dams, partial coefficient of materials is shown in Table 7, partial coefficient of loading is shown in Table 8, and structural coefficient is shown in Table 9.

Table 7 Partial coefficient of materials

Item		Material performance		partial coefficient
1	shear strength	Concrete /foundation	Fraction coefficient f'	1.3
			adhesive strength c'	3.0
		Concrete / Concrete	Fraction coefficient f'	1.3
			adhesive strength c'	3.0
2	Concrete strength			1.5

Table 8 Partial coefficient of loading

Item	Type of loading	partial coefficient
1	Weight	1.0
2	Water pressure	1.0
3	Seepage	1.2
4	Float force	1.0
5	Sand sediment pressure	1.2

Table 9 Structural coefficient

Item	Project	Combinations	Structural coefficient
1	Stability limiting state	Fundamental	1.2
		Accidental	1.2
2	Concrete strength limiting state	Fundamental	1.8
		Accidental	1.8

3.2 Analysis integer stability

The rigid balance theory is adapted to analysis integer stability. It is assumed that the grouting system and drainage system is effective. For spillway, the level of section which corresponds to integral stability is 1515.00 m. As we don't know what the foundation level of non-spillway is, we suppose that the foundation level of this section is also 1515.00 m, the same as the foundation level of the spillway.

Table 10 shows the reliability of integer stability of dam. The value of stability reliability is slightly deficient.

3.3 Stress analysis of dam body

(1) Analysis by material mechanics method

Based on engineering material mechanics method of DL5108-1999 Specification for Design Concrete Gravity Dam, Table 11 shows the stress at dam toe. It is indicated that body stress is compressive with fundamental combination, while tensile stress of −102.5 kPa at dam toe with accidental combination. The stress distribution satisfies specifications of China.

(2) Finite element method analysis

ANSYS (FEM software) is used to analyze the stress and deformation, the element model is plane42, Drucker-Prager model is adopted for foundation and concrete. The construction joints are simulated in detail in every 1500 mm, Table 12 shows material parameters.

The maximum horizontal deformation of spillway dam is 1.03 mm, appearing on dam crest, and the maximum tensile stress is 0.30 MPa at dam toe, satisfied with specifications.

(3) Reliability analysis

Overload method is adapted to analyze the reliability of dam safety, the safety factor means the mutant-point of curve deformation (or its derivative)-overload coefficient. Table 13, Fig. 12 and Fig. 13 present the overload coefficient vs crest deformation and its derivative, and table 14 presents the safety factor k of stability required by SL253-2000 Design Specification for Spillway. It is indicated that the safety factor is 3.2, which satisfies 3.0 required in SL253-2000 Design Specification for Spillway.

Table 10 Integer stability reliability of dam

Water level /m		Loading function	Resistance capability	Result	
Upstream	downstream			Spillway	non-spillway
1545.00	1521.50	5057 kN	4987 kN	instability	
1545.00	1521.50	5057 kN	4890 kN		instability
1547.60	1521.50	5059 kN	4874 kN		instability

Table 11 Stress distribution of dam body

Water Level/m		Stress distribution/kPa			
		Spillway		Non-spillway	
		Max.	Min.	Max.	Min.
Upstream Downstream	1545.00 1521.50	517.2	60.3	536.1	51.3
Upstream Downstream	1547.60 1521.50			686.8	−102.5

Table 12 Material parameters

Type	E/GPa	μ	γ/(kN • m^{-3})	φ /(°)	c/MPa
Concrete	28.5	0.167	24.0	45.0	1.50
Foundation	29.0	0.30	16.7	45.0	1.50
Joints	22.8	0.167	24.0	39.0	0.25

Table 13 Overload coefficient vs crest deformation

coefficient	1.0	1.5	2.0	2.8	3.0	3.2	3.5
Deformation /mm	0.99	1.73	2.57	4.33	4.92	5.63	7.00
Derivative of deflection		1.15	1.58	2.20	2.95	3.53	4.60

Table 14 Safety factor *k* of stability

Load case		*k*
Fundamental case		3.0
Accidental case	(1)	2.5
	(2)	2.3

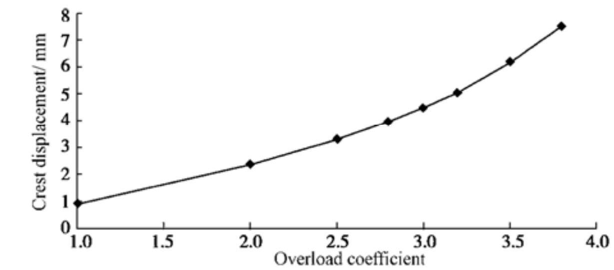

Fig. 12 Variation of overload coefficient vs crest deformation

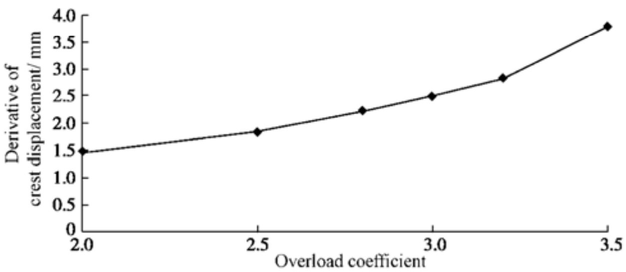

Fig. 13 Variation of overload coefficient vs derivative of crest deflection

4 Reliability assessment and repair

Safety, function and durability of the dam are affected by cracks and horizontal construction joints. Integral stability and stress level especially tension stress at upstream dam toe are very important to dam. All assessment and repair suggestion are present.

4.1 Reliability assessment

The content of reliability assessment is dam safety, dam function and concrete durability. It is recognized that cracks and horizontal construction joints are the most difficult problems all around the world, and the assessments focus on the effects of them.[4]

(1) Dam safety

Cracks and horizontal construction joints are classified into 3 grades:

Dangerous cracks: Decreasing dam reliability down, and endangering stabilization of dam.

Significant cracks: Decreasing dam reliability down obviously, while dam keeping stabilization.

General cracks: Decreasing the reliability down slightly.

(2) Dam function

Cracks and horizontal construction joints are classified into 2 grades:

Dangerous cracks: Arising economic loss and disaster for dam and downstream, such as flood control and adjustment, hydropower and irrigation, endangering lives of inhabitant;

General cracks: Decreasing the function and safety a little.

(3) Concrete durability[5]

Dam durability is endangered by horizontal construction joints and cracks, such as concrete carbonation, loosening, desquamation, leakage, etc.

(4) Reliability assessment

Dam safety and function are most important content during reliability assessment of Gandjelas gravity dam with cracks and horizontal construction joints.

According to inspection, the depth of main upstream horizontal construction joints is 500 mm, while that of minor construction joints is 200 mm, so as on the wall of corridor. As a result, the integral stability is decreased and endangered dam safety according to DL5108-1999-Design Specification for Concrete Gravity Dams. Therefore, dangerous cracks are defined as viewed from dam safety.

Caused by cracks of upstream face, the function of anti-permeation on concrete face disappeared. Influenced by leakage of dam and corridor, some functions, such as flood control and adjustment, hydropower and irrigation is greatly reduced during dam

Table 15 Result of integral stability (strengthening)

Water level/ m		Loading function	Resistance capability	Result	
Upstream	Downstream			Spillway	Non-spillway
1545.00	1521.5	5057 kN	5243 kN	Stability	
1545.00	1521.5	5057 kN	5147 kN		Stability
1547.60	1521.5	5059 kN	5129 kN		Stability

operating. Therefore, dangerous cracks are defined as viewed from dam function.

It is difficult to exactly assess concrete durability with horizontal construction joints and cracks. However, it is obvious that dam durability is endangered by horizontal construction joints and cracks, such as concrete carbonation, loose, desquamation, leakage, etc. Therefore, dangerous cracks are defined as viewed from dam durability.

Considering dam safety, function and concrete durability, dangerous cracks is defined as cracks and horizontal construction joints. Thus, it is necessary to dispose cracks and horizontal construction joints.

4.2 Suggestion for strengthening and repair[6]

Pre-stress anchor system and anti-permeation system are suggested to solve the delaminating of construction joint and dam leakage. Pre-stress anchor system should be adopted on upstream of the dam to improve reliability of integral stabilization and anti-permeation system should be adopted to protect dam from corrosion by seepage water through upstream joints, interface and interior default.

Pre-stress anchor system is set from corridor to dam foundation. Line anti-permeation system and surface anti-permeation system are two parts of the anti-permeation system. For the main upstream horizontal construction, two anti-permeation systems are suggested, while surface anti-permeation system is used for minor construction joints. Grouting permeability reducing admixture (epoxy liquid) is used for the cracks and joints of the upstream surface, sealant material is used to Seal the cracks on the surface, and impervious crystal cement material is coated on the upstream surface, NBS mortar is suggested on the spillway. Grouting permeability reducing admixture (epoxy liquid) is used for cracks on the wall along the corroder.

(1) Pre-stress anchor system

Pre-stress anchor system for spillway dam is located on surface of bottom corridor, 3000 mm next to upstream face, the pre-stress acted as 500 kN/m. Table 15 shows integral stability after strengthening, with its resistance capability larger than loading function, it is indicated that the integral stability satisfies specifications.

Considering the economic, and time limit of construction, three number of pre-stress anchor system are arranged symmetrically for dam structural 4#, A#, B#, C#, 5#. As a result, the unitary design pre-stressing is 1750 kN, and there shall be 15 systems of anchoring.

(2) Upstream horizontal construction Joints

For main construction joints and cracks, grouting permeability-reducing admixture (epoxy liquid) is used for the cracks and joints of the upstream surface, sealant material is used to seal the cracks on the surface, and impervious crystal cement material is coated on the upstream surface. Fig. 14 shows the repairing technique of construction joints and cracks. For minor construction joints and cracks, impervious crystal cement material is coated on the whole upstream surface.

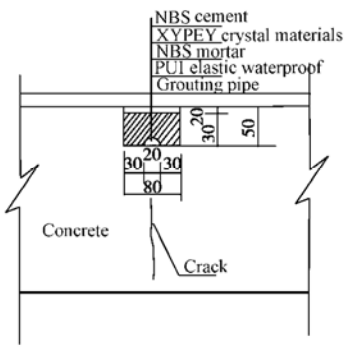

Fig. 14 Solving methods on level construction joint

(3) Horizontal construction joints in corridor and spillway

Loosening, desquamation and abrasion are common defects to the concrete spillway. To deal with the illnesses, NBS mortar is suggested on the spillway repairing and maintenance, to prevent water from penetrating into corridor, the elastic sealing material is used to seal cracks on the spillway concrete.

Grouting permeability-reducing admixture is used to repair the horizontal construction joints and cracks on the wall of corridor.

5 Conclusions and suggestions

(1) It is indicated that construction joints are main cracks in the dam. The depth of main cracks is about 600 mm, while depth of minor cracks is 200 mm. integrity of dam is deceased by the cracks, leakage inevitably occurs after water level rising.

(2) Based on DL5108-1999 Design Specifications for Concrete Gravity Dams, integral stability reliability is slightly deficient, and stress distribution of the dam body satisfies design specifications.

(3) Considering structural safety, function and durability of the dam, horizontal construction joints are justified as dangerous cracks, which are necessary to be repaired.

(4) Pre-stress anchor system and anti-permeation system are suggested to solve the delaminating of construction joint and dam leakage. Pre-stress anchor system should be adopted on upstream to improve reliability of integral stabilization, which is decreased by uncertainty of shear reliability in construction joints, and anti-permeation system be adopted to protect dam from corrosion by seepage water through upstream surface, interface and interior defaults. NBS mortar is suggested to be used on the spillway repairing and maintenance, and grouting permeability reducing admixture be used to repair the horizontal construction joints and cracks on the wall of corridor.

(5) To ensure the dam integral stability and dam safety, it is suggested that the safety monitor system be adopted during the construction of anchoring and operation.

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