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Code for seismic design of hydraulic structures of hydropower project

水电工程水工建筑物抗震设计规范

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2 Terms and symbols

2.1 Terms

2.1.1 Seismic design

Special design for the engineering structure of the strong earthquake zone. It generally includes two aspects: seismic calculation and seismic measure.

2.1.2 Basic intensity

Within the 50-year period, under general site conditions, it may encounter the seismic intensity of which the exceeding probability P_{50} is 0.10. Generally, the corresponding seismic intensity value is determined in accordance with the Appendix [in GB 18306], in accordance with the seismic peak acceleration value as indicated in GB 18306 for the site.

2.1.3 Design intensity

The seismic intensity determined as the basis for engineering fortification based on the basic intensity.

2.1.4 Reservoir earthquake

Earthquakes associated with reservoir impoundment that generally occur within 10 km of the reservoir bank.

2.1.5 Maximum credible earthquake

Earthquakes with the greatest ground motion that may occur at sites which are evaluated in accordance with the seismic geological conditions of the project site.

2.1.6 Scenario earthquake

Among the potential sources that may generate peak acceleration of ground motion at the site, the earthquake with the magnitude and epicentral distance that is determined along the main fault location in accordance with the principle of the maximum probability of occurrence.

2.1.7 Seismic ground motion

Geotechnical movement caused by earthquakes.

2.1.8 Seismic action

The dynamic action of ground motion on the structure.

time history.

2.1.18 Mode decomposition method

The method of firstly solving the seismic effect of the structure corresponding to its various modes at each stage and then combining them into the structure total seismic effect. The direct superimposing of the mode effects of each stage obtained by time-history analytical method is called mode decomposition time-history analytical method, whilst the combination of those obtained by reaction spectrum is called mode decomposition reaction spectrum method.

2.1.19 Square root of the sum of the squares (SRSS) method

The mode combination method of taking the square root of the sum of squared seismic effects of various modes as the total seismic action.

2.1.20 Complete quadratic combination (CQC) method

The mode combination method of taking the square of the seismic effect of each mode and the square root of the sum of the coupling items of different vibration modes as total seismic effect.

2.1.21 Seismic hydrodynamic pressure

The dynamic pressure exerted by the water body on the structure due to seismic effect.

2.1.22 Seismic earth pressure

The dynamic pressure exerted by the soil on the structure caused by the earthquake.

2.1.23 Quasi static method

The static analytical method of using the product of gravity action, the ratio of design seismic acceleration to gravity acceleration, and the given dynamic distribution factor as the designed seismic force.

2.1.24 Seismic effect reduction factor

A factor that is introduced to reduce the seismic effects due to the simplification of the calculation method of the seismic effect.

2.1.25 Natural vibration period

The time required for the structure to complete a free vibration in accordance with a certain mode. The natural vibration period corresponding to the first mode is called the basic natural vibration period.

years is 0.10 for the hydraulic structures of categories other than category A, but it shall also not be less than the corresponding seismic horizontal acceleration divisional value in the divisional map.

3 For the hydraulic structures, of which the engineering seismic fortification is category A, which requires specific site seismic safety evaluation, in addition to performing seismic design based on the design seismic peak acceleration, it shall make specific demonstration for the safety margin of avoiding uncontrolled drainage catastrophe of reservoir water when it is subject to the maximum credible earthquake of the site, and propose the seismic safety theme report it is based on, wherein: the horizontal peak acceleration representative value of the "maximum credible earthquake" shall be determined in accordance with the seismic geological conditions of the site, using the deterministic method or the result of the probability method of which the exceeding probability P_{100} within 100 years is 0.01.

4 When the backwater structure is upgraded from grade 2 to grade 1 due to dam height and seismic geological conditions, in addition to performing seismic design based on the horizontal design seismic peak acceleration of which the exceeding probability P_{50} within 50 years is 0.10, it shall also be based on the horizontal design seismic peak acceleration of which the exceeding probability P_{100} within 100 years is 0.05 to perform specific demonstration for the safety margin of avoiding uncontrolled drainage catastrophe of reservoir water.

5 In the special report on seismic safety, the site-related design response spectrum should be determined in accordance with the scenario earthquake corresponding to the horizontal design seismic peak acceleration, and produce the manually simulated seismic acceleration time-history based on this; for the strong nonlinearity analysis of the structural seismic effect, it should study the influence of the non-stationary frequency of ground motion; when the seismic fault is less than 30 km from the site and the inclination angle is less than 70°, it should be included in the influence of the hanging wall effect; when the distance from the site is less than 10 km and the magnitude is greater than 7.0, it should study the process that, in the near-field large earthquake, the seismogenic fault acts as the surface source rupturing, to directly generate the random seismic acceleration time-history of the site, and take-use the time-history of which the asymptotic spectrum peak period is most approaching to the basic period of the structure.

6 The short-term condition during the construction period can be exempted from combining with the seismic action.

4.2 Foundation

4.2.1 The seismic design of the foundation of a hydraulic structure shall take into account the type, load, hydraulic and operating conditions of the upper structures, as well as the engineering geological and hydrogeological conditions of the foundation and bank slope.

4.2.2 For foundations and bank slopes of dams, sluices, and other backwater structures, it shall meet the requirements for no failure of strength instability (including sand liquefaction, soft cohesive soil subsidence, etc.) and seepage deformation under the seismic action of design intensity, to avoid harmful deformation that affects the use of the structures.

4.2.3 The weak structural planes such as ruptures, fracture zones and interlayer displacements in the foundations and bank slopes of hydraulic structures, especially the gently inclined angled mud layers and rock layers that may be muddy, shall be subject to demonstration that it does not cause instability or unallowed deformation under the seismic action based on their occurrence and burial depth, boundary conditions, seepage conditions, physical and mechanical properties, and it shall take seismic measures if necessary.

4.2.4 The anti-seepage structure of the foundation and bank slope of the hydraulic structure and its connection parts, as well as the drainage filtration structure shall take effective measures to prevent harmful cracks or osmotic damage during the earthquake.

4.2.5 For the uneven foundations with large changes in the horizontal direction such as geotechnical properties and thicknesses, it shall take measures to avoid large uneven settlement, slippage and concentrated leakage during earthquakes, and take measures to improve the upper structure’s ability to adapt to the uneven settlement of the foundation.

4.2.6 The determination of soil liquefaction category in the foundation shall be carried out in accordance with the relevant provisions of GB 50287 Code for hydropower engineering geological investigation.

4.2.7 For the liquefiable soil layer in the foundation, it can be based on the project type and actual conditions to select the following seismic measures:

1 Excavate the liquefied soil layer and replace it with non-liquefied soil;

2 Artificial densification such as vibrating densification and strong blow compaction;

3 Ballasting and drainage;

5 General in earthquake action and seismic analysis

5.1 Seismic action components and its combination

5.1.1 In general, hydraulic structures other than aqueducts may only consider horizontal seismic action.

5.1.2 The following grade 1 and 2 hydraulic structures of which the design intensity is VIII and IX: the backwater structures such as embankment dams and gravity dams, long cantilever, large-span or towering hydraulic concrete structures shall take into account the horizontal and vertical seismic action simultaneously. The representative value of the vertical design seismic acceleration can generally take 2/3 of the representative value of the horizontal design seismic acceleration. For the near-site earthquake, it shall take the representative value of the horizontal design seismic acceleration.

5.1.3 For special types of arch dams with severe asymmetry and void, as well as the grade 1 and 2 double-curved arch dam of which the design intensity is VIII and IX, it should perform specific study for its vertical seismic effect.

5.1.4 For horizontal seismic action, in general, in the seismic design of embankment dams and concrete gravity dams, it may only take into account of the horizontal seismic action along the river flowing direction. For the gravity dam section on the steep slope of the two banks, it should take into account of the horizontal seismic action perpendicular to the river flowing direction; for important embankment dams, it should make special study for the horizontal seismic action perpendicular to the river flowing direction.

5.1.5 For the concrete arch dam and sluice, it shall consider the horizontal seismic action along the river flowing direction and that perpendicular to the river flowing direction.

5.1.6 For the hydraulic concrete structure with the similar lateral stiffness along the two main axial directions, such as the intake tower and the sluice top frame, it shall consider the horizontal seismic action of the structure along the two main axial directions.

5.1.7 When the mode decomposition method is used to simultaneously calculate the seismic effects in mutually orthogonal directions, the total seismic effect may take the square root value of the sum of the squares of the seismic effects in mutually orthogonal directions.

6 Embankment dam

6.1 Seismic calculation

6.1.1 Seismic calculation shall include seismic stability calculation, permanent deformation calculation, anti-seepage safety evaluation and liquefaction determination, etc., the comprehensive evaluation of seismic safety is performed combined with seismic measures.

6.1.2 For the seismic stability calculation of embankment dams, the quasi-static method is generally used to calculate the seismic effects. When one of the following conditions is met, the finite element method shall be used simultaneously to perform the dynamic analysis for the seismic effect of the dam body and the dam foundation, to judge comprehensively its seismic stability.

1 Design intensity VII and dam height of 150 m or more;

2 Design intensity VIII, IX and dam height of 70 m or more;

3 When the thickness of the cover layer exceeds 40 m or there is a liquefiable soil layer in the dam foundation.

6.1.3 When the quasi-static method is used to calculate the seismic effect and the seismic stability calculation is carried out for the embankment dam, it should be based on the slip-arc method based on the force between the strips to make verification in accordance with clause 5.7.1 of this Code, the calculation formula is as shown in Appendix A. For foundations with thin soft clay interlayers, as well as thin inclined wall dams and thin core wall dams, it may use the slip wedge method for calculation.

6.1.4 When the quasi-static method is used to calculate the seismic effect and the seismic stability calculation is carried out for the embankment dam, the dynamic distribution factor of the seismic inertia force of the particle i shall be adopted in accordance with the provisions of Table 6.1.4. In the table, the α_m is taken as 3.0, 2.5, and 2.0 when the design intensity is VII, VIII, and IX.

6.1.5 When the embankment dam uses the quasi-static method to calculate the seismic effect and the seismic stability calculation is carried out, for the grade 1 and 2 embankment dam, it should use the dynamic test to determine the dynamic shear strength of the soil body. When the dynamic strength given by the dynamic test is higher than the corresponding static strength, it shall take the static strength value.

For non-liquefied soils such as cohesive soil and compact sand gravel, when

6.2 Seismic measure

6.2.1 For the construction of embankment dams in strong earthquake areas, it should use the dam axis that is curved straight or upstream. It should not adopt a dam axis that is curved downstream, folded or S-shaped.

6.2.2 When the design intensity is VIII and IX, it should select the rockfill dam, the anti-seepage body should not adopt the type of rigid core wall. When using a homogeneous dam, it shall set an internal drainage system to lower the immersion line.

6.2.3 The safety freeboard of embankment dams in strong earthquake areas shall include earthquake surge height and earthquake subsidence, which can be determined in accordance with the following principles:

1 In accordance with the design intensity and the water depth in front of the dam, the earthquake surge height is taken as 0.5 m ~ 1.5 m.

2 When the design intensity is VII, VIII, IX, the safety freeboard shall take into account of the seismic subsidence of the dam and foundation.

3 For the surges that may be formed by large-scale collapse and landslides in the reservoir area due to earthquakes, it shall perform special research.

6.2.4 When the design intensity is VIII or IX, it should widen the dam crest and slow down the upper dam slope. The foot of the slope can be covered or ballasted, the upper dam slope can be protected by a masonry block stone, the upper dam slope can be reinforced with reinforcing steel, geosynthetic materials or concrete frame.

6.2.5 It shall appropriately improve the seismic indicators of the embankment dam anti-seepage body in the strong earthquake area, especially the top of the dam which may crack during earthquake and the connection part between the dam body and the bank slope or concrete structure. The joint surface of the anti-seepage body and the bank slope or concrete structure shall not be too steep, the slope changing angle should not be too large, there shall be no anti-slope and sudden slope change; it shall appropriately thicken the anti-seepage body and its anti-filter layer and transition layer upstream and downstream of it.

6.2.6 It shall select the earth and rock materials with good seismic performance and permeability stability and good grading for dam construction. Uniform medium sand, fine sand, grit and silt should not be used as dam materials in strong earthquake areas.

6.2.7 For the compaction function and compaction of cohesive soils and the filling dry density or porosity of the rockfill, it shall be carried out in accordance

7 Gravity dam

7.1 Seismic calculation

7.1.1 For the seismic calculation of gravity dams, it shall perform the dam strength and the overall anti-sliding stability analysis along the construction base plane. For roller compacted concrete gravity dams, it shall also perform the anti-sliding stability analysis along the rolling layer.

7.1.2 For the seismic analysis of gravity dams, generally the highest dam section of different types of dam sections can be taken, which is carried out in accordance with a single dam section. For gravity dams with significant overall actions, it should perform the comprehensive analysis for the entire dam section.

7.1.3 The seismic calculation of gravity dam can be performed by dynamic method or quasi-static method. the seismic effects of the gravity dam of the engineering seismic fortification category A, or that of the engineering seismic fortification category B and C but the design intensity VIII and above or the dam height higher above 70 m shall be calculated by the dynamic method.

7.1.4 The overall anti-sliding stability analysis of the gravity dam along the foundation base plane and the anti-sliding stability analysis along the rolling compaction layer shall be calculated in accordance with the shear strength formula in the rigid body limit equilibrium method. For the deep anti-sliding stability problem, the rigid body limit equilibrium method based on the equal safety factor method (also known as the equal-K method) shall be taken as the basic analysis method. For gravity dams with complex geological conditions, it should supplement nonlinear finite element analysis.

7.1.5 For gravity dams with a dam height greater than 70 m, the strength safety shall subject to the finite element method analysis in addition to the material mechanical calculation of dynamic and static force. For the gravity dam of the engineering seismic fortification category A or with complex structure or with complex geological conditions, it shall consider the nonlinear influence such as materials when performing finite element analysis. For gravity dams that shall be subjected to seismic calculation under the maximum credible earthquake, special studies shall be carried out using the finite element method that accounts for the nonlinear characteristics of the dam and foundation.

7.1.6 The dynamic analysis method of gravity dam shall adopt the mode decomposition method. For the gravity dam of which the seismic fortification category A, it shall increase the calculation evaluation of nonlinear finite element method.

7.1.7 Under the design earthquake, the dynamic method is used to check the

the rock mass shall take the static mean value, the partial factor shall be 1.0, the structural factor of anti-sliding stability shall not be less than 1.40; or otherwise it shall use the time-history analysis method to perform comprehensive analysis judgement of the seismic stability of the potential sliding rock mass of the abutment.

8.1.10 When using the time-history analysis method to comprehensively analyze and evaluate the seismic stability of the potential sliding rock of the abutment, the following steps shall be taken:

1 Under the action of the three components of the design ground motion, the time-history analysis method is used to calculate the combined time-history of static and dynamic integration of the arch end, and it acts on the potential sliding rock mass together with the inertial force of the rock mass without the power amplification effect.

2 In each time step, the structural factor of the stability of the abutment rock mass is calculated in accordance with the rigid body limit equilibrium method, to provide the time-history of the structural factor changes with time in the whole seismic process, and the minimum value of the structural factor in the time-history is used to evaluate the abutment seismic stability.

3 If the minimum value of the structural factor time-history does not meet the requirements specified in clause 8.1.9, it shall be based on the duration and extent of the stability index overrun, to comprehensively evaluate the anti-sliding stability of the potential sliding rock of the abutment as well as its impact onto the integral safety of the dam.

8.1.11 In the seismic calculation analysis of important arch dams fortified with the maximum credible earthquakes, it shall take into account of the impacts of dam transverse joint and the contact nonlinearities forming the controlled slipping plane in the dam foundation, the material nonlinearities of the main weak belts in the near-site bedrock, and the radiation damping effect of the far-site foundation. For important arch dams within the scope of clause 3.0.6, it shall be based on the calculation analysis and model test, combined with the engineering comparison, in accordance with the fortification requirements of the catastrophic failure of the reservoir water out of control, to perform the comprehensive evaluation.

8.1.12 When the seismic analysis and evaluation of the dam is carried out in accordance with the provisions of clause 8.1.11, the inflection point on the curve of the typical deformation of the dam or bedrock changed with the increase of the seismic action may be used as the evaluation index for the overall safety of the dam foundation system, at this time, the ratio of the seismic acceleration value to the design seismic acceleration is used as the safety margin for the dam to avoid uncontrolled drainage catastrophe of reservoir water.

by the formula (7.1.14) can be converted into the waterfront additional mass corresponding to the unit seismic acceleration for consideration.

9.1.8 The representative value of the seismic active earth pressure acting on the sluice side pier or side wall and wing wall may be calculated in accordance with the provisions of clause 5.9.1.

9.1.9 The structural strength of each component of the sluice structure shall be subject to seismic verification in accordance with clause 5.7.4 and comply with other relevant provisions of the SL 265 Design specification for sluice. It shall check the influence of the structural deformation of each part of the sluice during earthquake on the operation of the hoisting equipment.

9.1.10 The anti-sliding stability along the bottom surface of the sluice foundation shall determine the seismic effect in accordance with this Code and comply with other relevant provisions of SL 265. When the dynamic method is used to calculate the seismic stability of the sluice, it shall use the seismic effect consistent with the strength verification.

9.1.11 For the sluice on the rock foundation, when using the dynamic method or quasi-static method to check the anti-sliding stability along the foundation bottom surface or the shallow layer of sluice foundation, it can make reference to the provisions of 7.1.7 or 7.1.15, respectively; for the sluice on the soil foundation, when using the quasi-static method to verify the anti-sliding stability along the foundation bottom surface or the shallow layer of sluice foundation, the structural factor shall be taken as 1.2.

9.2 Seismic measure

9.2.1 When the pile foundation is used for the sluice foundation, the connection between the pile foundation and the sluice bottom plate and the anti-seepage measures shall be taken. The bottom plate may be provided with measures such as anti-seepage wall, tooth wall and tail sill, to prevent the foundation from being separated from the sluice bottom plate due to seismic action, thus causing piping or concentrated seepage.

9.2.2 The arrangement of the sluice chamber structure shall be symmetrical and enhance the integrity. The sluice chamber shall adopt a reinforced concrete integral structure. The water-stop structure of the split joint shall be of a type and material that is durable and adaptable to large deformations, and the water-stop measures for the split joint of key parts shall be strengthened.

9.2.3 It should reduce the height of the rack bridge and reduce the weight of the top of the rack from the selection and arrangement of the sluice and hoist.

9.2.4 The frame bridge should adopt the frame structure, it shall strengthen the

11 Intake tower

11.1 Seismic calculation

11.1.1 The seismic calculation of the intake tower shall include the verification of the tower body stress or internal force, the overall anti-sliding and anti-overturning stability, and the bearing capacity of the foundation at the bottom of the tower. The non-structural components, the auxiliary electromechanical equipment and the joints with the structural body shall be subject to seismic design.

11.1.2 The dynamic method or quasi-static method shall be used to calculate the seismic effect of the intake tower. For the non-reinforced concrete structure intake tower of which the engineering seismic fortification is category A or the design intensity VIII and above or tower height greater than 40 m, it should use the dynamic method to calculate the seismic effects.

11.1.3 The dynamic analysis of the seismic effect of the intake tower shall consider the influence of the water body inside and outside the tower and the foundation, and it should use the mode decomposition method.

11.1.4 The seismic calculation model of the intake tower body can be considered as the variable section cantilever beam using the material mechanics method or the finite element method, but it shall be the same as the calculation mode used in the basic load combination analysis.

11.1.5 When quasi-static method is used to calculate the seismic effect of the intake tower, the representative values of the horizontal seismic inertial force of each particle shall be calculated in accordance with the provisions of clause 5.5.9, where G_{Ei} is the gravity action representative value of the tower body, framed bent and its subsidiary equipment which is concentrated at the particle i, the dynamic distribution factor α_i of seismic inertial force shall be adopted in accordance with Table 11.1.5. When the height of the building is H = 10 m ~ 30 m, α_m = 3.0, when H > 30 m, α_m = 2.0.

11.1.6 When using the dynamic method to calculate the seismic effect of the intake tower, the hydrodynamic pressure inside and outside the tower can be considered as the additional mass of the inner and outer surfaces of the tower, respectively, calculated in accordance with the formula (11.1.6).

$$m_w(h) = \psi_m(h)\rho_w\eta_w A\left(\frac{a}{2H_0}\right)^{-0.2} \quad (11.1.6)$$

calculated in accordance with the shear strength formula.

11.1.14 When verifying the foundation bearing capacity of the intake tower, the vertical positive stress on the base plane of the tower shall be calculated in accordance with the material mechanics method.

11.1.15 In the seismic verification, the anti-sliding stability structural factor of the intake tower shall be not less than 2.70. At this time, the shear strength parameter shall be static average, the anti-overturning stability structural factor shall be not less than 1.40; the foundation bearing capacity structural factor of the average vertical positive stress on the tower base plane and the edge maximum vertical positive stress shall be respectively not less than 1.20 and 1.00.

11.2 Seismic measure

11.2.1 The intake tower with high water head and large flow rate shall adopt a box-type structure with large rigidity, anti-overturning ability and bearing capacity, good integrity and good seismic performance. For the frame structure, it shall improve the strength and rigidity of the joints and support members, to ensure that the integrity of the structure and sufficient torsional rigidity.

11.2.2 Under the premise of meeting the operation requirements, the structure of the intake tower body shall be as simple and symmetrical as possible, the mass and stiffness are changed gently, the stress concentration is reduced, and there is sufficient lateral displacement stiffness. The lateral support shall be appropriately set along the tower height, and the rigidity of the support shall be strengthened at the sudden change of the section.

11.2.3 The tower body should be built on a rock foundation with sufficient bearing capacity and with appropriate burial depth to strengthen the consolidation grouting.

11.2.4 The gap between the tower body of the shore-type water intake tower and the excavated rock mass should be backfilled.

11.2.5 The weight of the tower hoisting machine room shall be reduced. At the seismic weak portions between the tower body and the traffic bridge and the bridge piers, it shall increase the overlapping area between the bridge deck and the tower top, take flexible connections and such measures as avoid the traffic bridge of the hoisting machine from shaking off during earthquake, and strengthen the seismic capacity of the pier.

11.2.6 The intake tower group should be arranged in rows and connected to each other to increase the lateral stiffness.

12.1.6 It should increase the flexibility of the pipe connection structure, to prevent the pipe from slipping off the support pier during an earthquake.

12.1.7 The joints and connection structures at the exit of the buried pipe in the gravity dam shall have good seismic performance.

12.2 Ground powerhouse

12.2.1 The seismic calculation principles and methods for the substructure of the powerhouse are the same as that of the concrete gravity dam.

12.2.2 The overall anti-sliding stability of the powerhouse under the design seismic effect may be calculated in accordance with the shear strength or shear strength formula, and it shall be carried out in accordance with the relevant provisions of NB/T 30511 Design code for hydropower station buildings.

12.2.3 The vertical positive stress on the foundation surface of the powerhouse shall be calculated in accordance with the material mechanics method under the design seismic effect. The verification of the bearing capacity of the bedrock and the tensile strength of the foundation surface shall be carried out in accordance with the relevant provisions of NB/T 35011. The standard value of the dynamic bearing capacity of the bedrock may be 1.50 times the static standard value.

12.2.4 The section bearing capacity of the superstructure of the powerhouse shall be subject to seismic verification in accordance with the relevant provisions of clause 5.7, and the acceleration at the top of the substructure shall be taken as the seismic input of the superstructure of the powerhouse.

12.2.5 The division seam type and water stop of the underwater part of the powerhouse shall meet the requirements of seismic resistance. It should use water stop materials and types with better seismic performance.

12.2.6 The seismic measures for the superstructure of the powerhouse shall be carried out in accordance with DL/T 5057 and the relevant provisions of GB 50011 Code for seismic design of buildings.

12.2.7 The shore powerhouse should be selected in a stable bank slope and ground conditions. The rear slope of the powerhouse shall avoid high steep cliffs and potentially unstable bank slopes. The rock slope after the powerhouse shall be excavated into stable slope, it should perform spray anchoring support, and take protective measures for the powerhouse at the rock slope side.

14 Shiplift

14.1 Seismic calculation

14.1.1 The seismic calculation of the tower column of the ship lift shall include deformation, strength verification, overall anti-sliding stability and anti-overturn stability verification.

14.1.2 When design intensity is VII and above, the impact of vertical earthquakes shall be considered.

14.1.3 For structures with uneven or asymmetrical mass or stiffness distribution, it shall study the impacts of torsional effects under horizontal earthquakes.

14.1.4 For tower column structure with a height not exceeding 30 m, it may use the quasi-static method to calculate its seismic effects, the dynamic distribution factor of the seismic inertial force can refer to the relevant provisions for the intake tower.

14.1.5 The seismic effects of the tower column structure with a height of more than 30 m shall be calculated by the mode decomposition reaction spectrum method. For the grade 1 tower column structure, it should perform the time-history analytical calculation.

14.1.6 For rack-and-pinion climb-type ship lift, the dynamic interaction between the ship cabin and the load-bearing tower structure as well as the influences of the dynamic fluid-solid coupling effect of the ship bearing tank water body shall be considered, the hydrodynamic pressure value in the steel structure ship cabin can be determined by referring to the provisions of clause 13.1.4.

14.1.7 When the tower is subject to dynamic analysis, if its structure is connected with the counterweight, it shall be connected through the springs of rigidity equivalent to that of the guide wheel and the guide rail, to perform the dynamic coupling analysis. Simplified analysis may add 30% of the counterweight mass to the tower column, to simulate the interaction of the counterweight with the tower column.

14.1.8 The non-structural components, auxiliary electromechanical equipment and their connection to the structural body of the ship lift structure shall be subject to seismic design.

14.2 Seismic measure

14.2.1 The tower structure of the ship lift should select a box-type structure with direction can be upward (-) or downward (+), the direction unfavorable to stability shall prevail;

M_h - Moment of E_h to the center of the circle;

r - The radius of the sliding arc:

θ_t - The angle between the radius of the sliding arc passing through the midpoint of the bottom surface of the strip and the plumb line passing through the center of the sliding arc; it is taken as positive when the radius deviates from the plumb line to the dam axis; otherwise, it is taken as negative;

b - The width of the sliding strip;

u - The pore water pressure representative value at the midpoint of the bottom surface of the strip;

z - The vertical distance of the water level outside the dam slope above the midpoint of the bottom surface of the strip;

γ_w - The bulk density of water;

c, φ - The cohesion and friction angle of the soil under seismic action;

γ_0 - The structural importance factor, which is valued in accordance with the provisions of GB 50199 Unified design standard for reliability of hydraulic engineering structures;

ψ - Design condition factor, which is taken as 0.85 in accordance with the provisions of clause 5.7.1;

γ_E - The partial factor of seismic action, which is taken as 1.0 in accordance with the provisions of 5.7.1;

γ_c, γ_f - The material property partial factor of the shear strength index of soil, γ_c = 1.2, γ_f = 1.05, the material property partial factory of the nonlinear shear strength index of coarse aggregates such as rockfill and gravel (the friction angle of the sliding plane of the soil) can be taken as γ_f = 1.1;

γ_d - Structure factor.

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