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Code for Seismic Design of Special Structures

构筑物抗震设计规范

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1 General Provisions

1.0.1 This code is formulated with a view to implementing the national laws and regulations on the seismic protection and disaster mitigation and the prevention-first policy so that the special structures can relieve seismic damage after seismic fortification to avoid casualties or complete loss of use function and minimize economic loss.

1.0.2 This code is applicable to seismic design of special structures at the area with Intensity 6 ~ Intensity 9 seismic precautionary intensity.

1.0.3 The seismic precautionary objective for the special structures, subjected to the seismic design according to this code, within 50-year design service life: the main structure shall not be damaged or not required to be repaired and may continue in service in case of being suffered from the frequent earthquakes below seismic precautionary intensity of this area; the damaged structure may continue in service after general repair in case of being suffered from precautionary earthquake equivalent to seismic precautionary intensity of this area; the integral collapse shall be avoided in case of being suffered from the rare earthquake higher than seismic precautionary intensity of this area.

1.0.4 The special structures with Intensity 6 or above seismic precautionary intensity must be subjected to seismic design.

1.0.5 The seismic precautionary intensity and the design parameters of ground motion must be determined according to the documents (graphic documents) approved and issued by the national authority and adopted according to the approval documents.

1.0.6 The seismic precautionary intensity shall adopt the basic seismic intensity in the current national standard "Seismic Ground Motion Parameter Zonation Map of China" GB 18306 or the intensity corresponding to the design basic acceleration value of ground motion in this code. The engineering site subjected to the seismic safety evaluation should be subjected to seismic fortification according to approved seismic precautionary intensity or the design parameters of ground motion.

1.0.7 The seismic design of special structures shall meet not only the requirements stipulated in this code, but also the provisions of the related current national standards.

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2 Terms and Symbols

2.1 Terms

2.1.1 Basic seismic intensity
The seismic intensity that may be met at general site conditions with a probability over 10% within a term of 50 years, which is equivalent to the seismic intensity once in 475 years.
2.1.2 Seismic precautionary intensity
The seismic intensity approved by national authority as the seismic precautionary basis of an area, generally using basic seismic intensity.
2.1.3 Seismic precautionary criterion
The standard for judging the seismic precautionary requirements, which is dependent on the seismic precautionary intensity or the design parameters of ground motion and the seismic precautionary category of special structures.
2.1.4 Earthquake action
The dynamic action of structure caused by ground motion, including horizontal earthquake action and vertical earthquake action.
2.1.5 Design parameters of ground motion
The seismic acceleration-time curve (speed and displacement), the response spectrum of acceleration, and the peak acceleration used in seismic design.
2.1.6 Design basic acceleration of ground motion
The design value of seismic acceleration exceeding the probability of 10% during the 50-year design reference period.
2.1.7 Characteristic period of ground motion
The period value corresponding to the starting point of the descending branch reflecting such factors as the earthquake magnitude, epicentral distance and site class in the seismic influence coefficient curve used for the seismic design.
2.1.8 Seismic influence coefficient
The assembly average of the ratio between the maximum acceleration reaction and gravity acceleration of single-particle elastic system under the earthquake action.
2.1.9 Site
The place where the engineering groups with similar response spectrum features are located.
2.1.10 Seismic concept design of special structures
The design process of making the process arrangement and structural selection for the special structures and of determining detailed constructions, based on the design fundamental design principles and design concept obtained from the past experiences in earthquake disasters and projects.
2.1.11 Seismic action effect
Internal force (shear-force, bending moment, axial force and torsion moment, etc.) or deformation (linear displacement and angular displacement, etc.) of the structure under the earthquake action.

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2.1.12 Modified coefficient of seismic action effect

The coefficient for modification of seismic action effect in the structure or components design influenced by the simplification of structural calculation model and redistribution of elastic-plastic internal force or other factors.

2.1.13 Modified coefficient of seismic bearing capacity

The coefficient for modifying the design section bearing capacities, which are specified in different codes for the design of material structures, into the design seismic bearing capacity in the seismic checking of structural components sections, as there are differences in the static force, seismic design reliability and seismic performance between different components.

2.1.14 Seismic measures

The seismic design excluding the earthquake action calculation and resistance calculation, including basic requirements of seismic design, details of seismic design and seismic measures of soil and foundation.

2.1.15 Details of seismic design

All the detailed requirements that must be taken for the structural and nonstructural parts according to seismic concept design principles, requiring no calculation generally.

2.2 Symbols

2.2.1 Action and action effect

F_{Ek} and F_{Evk} -- Characteristic value for total horizontal and vertical earthquake action of the structure;

G_E and G_{eq} -- Representative value of structure (component) gravity load and total equivalent gravity load in earthquake;

w_k -- Characteristic value of wind load;

S_E -- Seismic action effect (bending moment, axial force, shear-force, stress and deformation);

S -- Fundamental combination of seismic action effect and other load effects;

S_k -- Effect of action or characteristic value of load;

M -- Bending moment;

N -- Axial force;

V -- Shear-force;

p -- Pressure on bottom of foundation;

u -- Lateral displacement;

θ -- Displacement angle of structural layers.

2.2.2 Material properties and resistance

K -- Stiffness of structure (component);

R -- Bearing capacity of structural component;

f, f_k, f_E -- Design value, characteristic value and seismic design value of various material strength (including the bearing capacity of soil) respectively;

E -- Elasticity modulus of the material;

$[\theta]$ -- Displacement angle limit of structural layers.

2.2.3 Geometric parameters

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A -- Sectional area of component;

A_s -- Sectional area of rebar;

B -- Total width of structure;

H -- Total height of structure, or the column height;

L -- Total length of structure (unit);

a -- Distance;

a_s and $a_s^{'}$ -- Minimal distance from the force concurrence point of all longitudinal tensile and compressive reinforcements to the margin of section;

b -- Sectional width of component;

d -- Depth or thickness of soil layer, or diameter of rebars;

h -- Height of calculation structural layers or sectional height of component;

l -- Component length or span;

t -- Seismic wall thickness, structural layers floor slab thickness, steel plates thickness, time.

2.2.4 Calculation coefficient

a -- Horizontal seismic influence coefficient;

a_{max} -- Maximum value of horizontal seismic influence coefficient;

a_{vmax} -- Maximum value of vertical seismic influence coefficient;

γ_G, γ_E, γ_w -- Partial coefficient of action;

γ_{RE} -- Modified coefficient of seismic bearing capacity;

ζ -- Damping ratio;

ε -- Structure type coefficient;

δ -- Basic vibration mode coefficient of structure;

η -- Increase or modified coefficient of seismic action effect (internal force and deformation);

λ -- Slenderness ratio, proportionality coefficient, correction coefficient and shear-span ratio of component;

ξ_y -- Yield strength coefficient of structure (component);

ρ -- Ratio of reinforcement, ratio, coupling coefficient;

φ -- Stability coefficient of compressive component;

φ -- Combination value coefficient and influence coefficient.

2.2.5 Others

T -- Fundamental period of structure;

N -- Penetration blow count;

I_{lE} -- Liquification index;

X_{ji} -- Vibration mode coordinate of displacement (relative displacement of the i^{th} mass of the j^{th} vibration mode in *x* direction);

Yji -- Vibration mode coordinate of displacement (relative displacement of the i^{th} mass of the j^{th} vibration mode in *y* direction);

n -- Total number, such as number of structural layers, particles, rebar, span, etc.;

v_{se} -- Equivalent shear-wave velocity of soil layer;

φ_{ji} -- Vibration mode coordinate of rotation (relative displacement of the i^{th} particle of the j^{th} vibration mode in rotating direction);

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avoided; active seismic measures shall be taken if it is impossible to be avoided.

3.3.2 It is forbidden to construct Class A and Class B special structures on the hazardous section determined by the comprehensive evaluation. The Class C special structures shall not be constructed thereon.

3.3.3 If the engineering site is of Class I, it is still allowed to adopt details of seismic design for Classes A and B special structures according to the requirements of local seismic precautionary intensity and adopt details of seismic design for the Class C special structures according to the requirements one grade less than the local seismic precautionary intensity, however, as for the seismic precautionary intensity 6, the details of seismic design shall be adopted according to the local seismic precautionary intensity.

3.3.4 If the engineering site is of Class III or IV, in the areas where the design basic acceleration of ground motion is 0.15g or 0.30g, unless otherwise stated in this code, the details of seismic design should be taken according to the requirements of special structures belonging to each seismic precautionary category respectively for basic acceleration of 0.20g (Intensity 8) and 0.40g (Intensity 9).

3.3.5 The design of soil and foundation shall meet the following requirements:

1 Foundation of one same structural unit should not be built on the soil with entirely different features.

2 The same structural unit should not adopt natural foundation and pile foundation at the same time; if different types of foundations are adopted or the buried depth of foundation is different obviously, corresponding measures shall be taken at the relevant positions of foundation and superstructure according to the differential settlement of these two parts of soils and foundations under earthquake and the analysis result on the structural response.

3 Where the liquefaction soil, soft clay, newly filled soil or extremely non-uniform soil are available within the range of major bearing stratum of the soils, appropriate measures shall be taken according to the degree of differential settlement of soils or other adverse effects under the earthquake.

3.3.6 Design of engineering site and soil and foundation at the mountain area shall meet the following requirements:

1 The survey on the engineering site in mountainous areas shall provide slop stability evaluation and prevention and treatment scheme suggestions; the side slope project in compliance with the seismic precautionary requirements shall be set up based on the geologic and topographical conditions and operation requirements.

2 The slope design shall meet the requirements of the current national standard GB 50330, "Technical Code for Building Slope Engineering"; and the relevant friction angle shall be corrected according to the precautionary intensity in stability checking.

3 The special structures foundation nearby the side slope shall be subjected to seismic stability design. The distance shall be sufficiently reserved at the edge of special structures foundation and soil or highly-weathered rocky side slope and determined depending on the seismic precautionary intensity; moreover, the measures shall be taken to protect the soil and foundation against damage in the earthquake.

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3.4 Structural System and Seismic Design Requirements

3.4.1 The design of special structures shall make the plan, elevation and vertical profile regular. The irregular special structures shall be provided with the strengthening measures as required; the extremely irregular special structures shall be subjected to special research and demonstration and then be provided with particular strengthening measures; the severely irregular structural design scheme shall not be adopted.

3.4.2 The structural system of special structures shall be determined after comprehensive comparison in technology, economy and service conditions according to factors like process and function requirements, seismic precautionary category, seismic precautionary intensity, structure height, site conditions, soil, structural material and construction; design of seismic isolation and energy dissipation may be adopted in case of Intensity 8 and Intensity 9.

3.4.3 The structural system shall meet the following requirements:

1 Clear calculation diagram and reasonable earthquake action transition ways shall be provided.

2 The integral structure shall be protected against loss of the seismic capacity or the bearing capacity on the gravity loads due to the damage of partial structure or components.

3 Seismic bearing capacity, deformability and seismic energy dissipation ability in conformity with this code shall be provided.

4 The measures shall be taken at the weak position to improve seismic capacity.

3.4.4 The structural system should meet the following requirements:

1 Enough seismic precautionary lines should be arranged.

2 The reasonable distribution of stiffness and bearing capacity should be provided to avoid the excessive stress concentration or plastic deformation concentration arising from the weak positions formed due to partial weakening or abrupt changes.

3 The cantilever structure with heavy deadweight should not be adopted.

4 The structure should have similar dynamic characteristics in the directions of two main axes.

3.4.5 The plane layout of lateral-resisting structure of special structures should be regular and symmetrical and the structure should change uniformly along vertical lateral displacement stiffness and the section dimension and material strength of vertical lateral-force-resisting components should be dwindled away upwards and the abrupt change of lateral displacement stiffness and bearing capacity of lateral-resisting structure should be avoided.

The seismic design of irregular special structures shall meet the relevant provisions of 3.4.7 in this code.

3.4.6 The plane and vertical irregularity of the special structure body and its member layout shall meet the following requirements:

1 The concrete structure, steel structure and steel-concrete structure, having any plan irregular type listed in Table 3.4.6-1 or horizontal irregular types listed in Table 3.4.6-2 or any similar irregular types, shall be regarded as irregular special structures.

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situation, and the position with large torsion shall be adjusted by local amplified coefficient of internal force.

2 The special structures in plan regularity and vertical irregularity shall adopt three-dimensional computation model, the seismic shear-force of storeys with small stiffness shall be multiplied by an amplified coefficient not less than 1.15, the weak layers shall be subjected to elastic-plastic deformation analysis according to the relevant regulations of this code and also shall meet the following requirements:

1) If the vertical lateral-force-resisting component is discontinuous, the seismic internal force transferred through this component to the horizontal transfer component shall be multiplied by an amplified coefficient of 1.25~2.0 according to the intensity, type, stress condition and physical dimension, etc. of the horizontal transfer component.

2) In case of the irregularity of lateral displacement stiffness, the lateral displacement stiffness ratio between adjacent layers shall comply with those specified in the relevant chapters of this code based on the structure type;

3) In case of the abrupt change of bearing capacity of the structural layers, the shear capacity of the lateral-force-resisting structure at the weak layers shall not be less than 65% of that of the adjacent upper layer.

3 The special structures in plan irregularity and vertical irregularity shall conform to the requirements at a degree not below than those in the first and second items depending on the irregular type number.

3.4.8 The special structures with complex shape and extremely irregular plan and elevation may be provided with the seismic joint at the proper position as required.

3.4.9 The seismic joint shall be left with adequate width according to the seismic precautionary intensity, category of structural material, structure type, height and height difference of structural units, and the superstructure on both sides of the seismic joint shall be separated completely.

3.4.10 To set expansion joint and settlement joint, their width shall comply with the requirements on seismic joint.

3.4.11 The structural components shall meet the following requirements:

1 The masonry structures shall be arranged with reinforced concrete ring beams, constructional columns and core columns as required or be adopted with reinforced masonry, etc.

2 As for the concrete structural component, the section dimension and arrangement of longitudinal stressed rebar and stirrup shall be controlled.

3 The prestressed concrete component shall be equipped with non-prestressed rebar.

4 The section dimension of steel structure component shall be controlled.

5 The concrete floor slab and roof of multi-layer special structures should adopt the cast-in-situ concrete slab. When adopting the precast concrete floor slab and roof, the measures to ensure the integral connection between each precast slab shall be taken.

3.4.12 The connection between components of the structure shall meet the following

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requirements:

1 The joint failure of component shall not occur before that of its connecting component.

2 Anchorage failure of embedded parts shall not occur before that of the connecting piece.

3 The connections of fabricated structural components shall ensure the integrality of the structure.

4 The prestressed rebar of prestressed concrete component should be anchored beyond the joint core zone.

3.4.13 The support system of special structures shall ensure the integrity and stability of the structure in case of the earthquake and the reliable transfer of the horizontal earthquake action.

3.5 Structural Analysis

3.5.1 The analysis for internal force and deformation of the structures on special structures shall be carried out according to the frequent earthquake action. In this analysis, it may be assumed that the structure and its components are working at elastic state, so that the analysis of internal force and deformation may be carried out in the linear static/dynamic method.

3.5.2 The special structures shall be subjected to elastic-plastic deformation analysis under the rare earthquake action according to the relevant requirements of this code when they are irregular and weak at some obvious positions and might be damaged seriously in case of earthquake. The elastic-plastic static analysis or elastic-plastic time history analyzing method may be adopted depending on the structural feature.

Where the specific provisions are specified in this code, the simplified methods calculating elastic-plastic deformations of the structures may be adopted.

3.5.3 When the gravity additional bending moment of structure under earthquake action is greater than 10% of the original bending moment, the influence of gravity second-order effect shall be taken into consideration.

3.5.4 In seismic analysis of structure, each structural layer shall be determined as the stiff, semi-stiff or flexible diaphragm according to the deformation on the plane, and then the collaboration between the lateral-force-resisting components may be determined according to the layout of lateral-force-resisting system and the internal force analysis of earthquake between components shall be carried out.

3.5.5 As for the structures having nearly symmetric distribution of masses and lateral displacement stiffness and structural layers regarded as stiff diaphragms as well as the structures with specific requirements in the relevant chapters of this code, the seismic analysis may be carried out in two-dimensional structural model. As for the other conditions, the seismic analysis may be carried out in the three-dimensional structural model.

3.5.6 The seismic analysis on the structure by computers shall meet the following requirements:

1 The determination of calculation model as well as simplified calculation and

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treatment shall comply with the actual working condition of this structure, and the effects of stair components shall be involved in calculation.

2 The technical conditions of calculation software shall comply with this code and those specified in the current relevant national standards, and the contents and reference of special treatment shall also be clarified.

3 The analysis for internal force and deformation of complex structures under frequent earthquake action shall adopt at least two different calculation procedures, and the calculation results of these two procedures shall be analyzed and compared.

4 The calculation result for calculation procedure shall not be used in the engineering design until it is analyzed and judged to be rational and effective.

3.6 Nonstructural Components

3.6.1 The nonstructural components, including the structural components, facilities and electromechanical equipment other than the main structure of the special structures, and their connection with the main structure shall be subjected to the seismic design.

3.6.2 The seismic design of nonstructural components shall be carried out by relevant professional personnel respectively.

3.6.3 The nonstructural components attached to structural layers and the non-bearing wall of staircase shall be reliably connected or anchored with the main structure and the adverse effect on the main structure shall be determined.

3.6.4 For the arrangement of enclosure walls and partition walls of main structure, their adverse effect on seismic performance of structure shall be analyzed and the irrational arrangement of these walls that would cause damage to major structure shall be avoided.

3.6.5 The nonstructural components nearby the personnel entrance/exit, passage and important equipment shall be provided with more safety measures.

3.7 Materials and Construction

3.7.1 The special requirements of seismic structures for materials and construction quality shall be clearly stated in the design documents.

3.7.2 The performance indexes of structural materials shall meet the following requirements:

1 The materials of masonry structure shall meet the following requirements:

1) The strength grade of common brick and perforated brick shall not be less than MU10 and the strength grade of their masonry mortar shall not be less than M5;

2) The strength grade of small hollow concrete blocks shall not be less than MU7.5 and the strength grade of their masonry mortar shall not be less than M7.5.

2 The materials of concrete structures shall meet the following

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requirements:

1) The strength classes of concrete for frame-supported beams and columns as well as frame beams and columns and joint core zone assigned to seismic Grade 1 shall not be less than C30; and the strength classes of concrete for structural column, core columns, ring-beams and other various components shall not be less than C20;

2) For the frame structure and diagonal bracing members (including the stair section) assigned to seismic Grades 1, 2 and 3, if ordinary rebars are used as their longitudinal stressed rebar, then the ratio between the measured tensile strength and the measured yield strength of rebar shall not be less than 1.25, the ratio between the measured value and characteristic value of yield strength shall not be greater than 1.3, and the measured overall elongation of rebar under the maximum tensile stress shall not be less than 9%.

3 The steels of steel structures shall meet the following requirements:

1) The ratio between the measured yield strength and measured tensile strength of steels shall not be greater than 0.85;

2) The steels shall have obvious yield steps and their elongation rate shall not be less than 20%;

3) The steels shall be provided with good weldability;

4) The steels shall be provided with impact toughness in compliance with the seismic design requirements.

3.7.3 The performance indexes of structural materials shall meet the following requirements:

1 The ordinary rebar should adopt the rebars with good ductility, toughness and weldability; as for the strength grade of ordinary rebar, the longitudinal stressed rebar should select HRB400E, HRB500E, HRBF400E, HRBF500E hot rolled rebars; the stirrup should select the HRB335 or higher hot rolled rebars in conformity with seismic performance index or HPB300 hot rolled rebars.

2 Inspection method of rebars shall meet the requirements of the current national standard "Code for Acceptance of Constructional Quality of Concrete Structures" GB 50204.

3 The concrete strength class of concrete structures, like seismic wall, should not exceed C60, and should not exceed C60 at intensity 9 and C70 at intensity 8 for other components.

4 Q235 should adopt the carbon structural steels of B, C, D quality grades; Q345 should adopt high strength low alloy structural steels of B, C, D, E quality grades; Q390, Q420 and Q460 should adopt high strength low alloy structural steels of C, D, E quality grades; other steel grades and types also may be used if there are reliable reference.

5 The foundation bolts of steel structure may select Q235-B, C, D or Q345-B, C, D, E steel.

3.7.4 During the construction, if the longitudinal stressed rebars in original design have to be replaced by those with higher strength grade, the conversion shall be made according to equal tensile capacity design values of such rebars, and shall also comply with requirement of minimum reinforcement ratio.

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action, the average pressure on foundation base and the maximum pressure on edge of foundation base according to the standard combination of seismic action effect shall meet the requirements of the following formulae:

$$p \leq f_{aE} \tag{4.2.4-1}$$

$$p_{max} \leq 1.2 f_{aE} \tag{4.2.4-2}$$

Where,

p -- the average pressure on foundation base according to the standard combination of seismic action effect;

p_{max} -- the maximum pressure on foundation edge according to the standard combination of seismic action effect.

4.2.5 The area of zero stress zone at foundation base shall meet the following requirements in checking seismic bearing capacity of natural subsoil:

1 As for special structures with regular shape, the area of zero stress zone shall not be greater than 25% of the foundation base area.

2 As for special structures with irregular shape, the area of zero stress zone should not be greater than 15% of the foundation base area.

3 As for the soar special structures with height to width ratio greater than 4, the area of zero stress zone shall be zero.

4.3 Liquefaction Soil

4.3.1 The liquification evaluation of saturated sandy soil and saturated silty soil (excluding loess) and the soil treatment may not be carried out under common conditions at Intensity 6, however, those of the Class B special structures that are sensitive to liquefaction settlement shall be carried out according to the requirements of Intensity 7 and those of Class B special structures of Intensities 7~9 may be carried out according to the requirements of local seismic precautionary intensity.

4.3.2 If saturated sandy soil and saturated silty soil are existed in under ground-surface, except for those of Intensity 6, all shall be subjected to the liquification evaluation; for the soil with liquefaction soil layer, corresponding measures shall be taken according to the seismic precautionary category of special structures and liquification degree of soil, in combination of the specific conditions.

Note: The liquification evaluation requirements for the saturated soil in this article exclude the loess and silty clay.

4.3.3 The saturated sandy soil or silty soil (excluding loess), if meeting any one of the following conditions, may be preliminarily evaluated as no liquefaction or slight liquefaction which is not included into the influence of liquification.

1 When geological age is quaternary late pleistocene epoch (Q_3) or previous time, the soil may be evaluated as non-liquefied soil at Intensity 7 and Intensity 8.

2 If the percentage content of silty soil particles (particles with grain size less than 0.005mm) is not less than 10%, 13% and 16% for Intensity 7, Intensity 8 and Intensity 9 respectively, the soil may be evaluated as non-liquefied soil.

Note: The sticky particle content used for liquification evaluation is measured using sodium hexametaphosphate as

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4.3.8 The measures partially eliminating the liquefaction settlement of soil shall meet the following requirements:

1 The treated depth shall make the liquification index of treated soil reduced and the value should not be greater than 5; as for the central area within the outer boundary of the large area raft foundation and box foundation where the distance to the outer boundary along the length and width directions is greater than a quarter of the corresponding direction, the treated liquification index should not be greater than 6; the individual foundation and strip foundation shall not be less than the larger value between the characteristic depth of liquefaction soil under foundation base and the foundation width.

2 After strengthening through vibro-flotation or gravel pile compaction, the standard penetration blow count of soil between piles should not be less than the critical value of standard penetration blow count for liquification evaluation as specified in Article 4.3.4 of this code.

3 The treated width outside the foundation edge shall meet the requirements of Item 5 in Article 4.3.7 of this code.

4 The other methods shall be taken to reduce the liquefaction settlement by increasing the thickness of upper covered non-liquefied soil layer and improving the drainage condition around.

4.3.9 The treatment of foundation and superstructure to reduce the liquification affect may use the following measures comprehensively:

1 Appropriate embedded depth of foundation shall be selected.

2 The bottom area of foundation shall be adjusted to reduce the eccentricity of foundation.

3 The box foundation, raft foundation or reinforced concrete crisscross foundation shall be adopted; the individual foundation shall be provided with the foundation coupling beam to strengthen the integrity and stiffness of the foundation.

4 The loads shall be reduced, the integral stiffness and uniform symmetry of superstructure shall be reinforced, the settlement joints shall be arranged reasonably, and the adoption of such structure form insensitive to differential settlement shall be avoided.

5 Adequate dimension shall be reserved or the flexible joints shall be adopted at the position where pipelines pass through the special structures.

4.3.10 No permanent special structures should be constructed within the sections with possibility of lateral expansion of liquification or flow-sliding, such as the fossil river course and sections near to the river bank, seacoast and side slope; otherwise, anti-sliding checks shall be carried out, and anti-sliding measures for the earth and measures for improving the structural integrity shall be taken.

4.4 Seismic Subsidence of Soft Soil

4.4.1 The special structures on the soft soil in Intensities 6 and 7, when the soil and foundation meet the relevant requirements of the current national standard "Code for Building Foundation" GB 50007, may not consider the influence of seismic subsidence

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conditions.

4 The measures taken at the foundation and superstructure shall meet the following requirements:

1) The box foundation, raft foundation and reinforced concrete crisscross foundation should be adopted;

2) The integral stiffness and uniform symmetry of superstructure shall be reinforced, the settlement joints shall be arranged reasonably, and the adoption of such structure form sensitive to differential seismic subsidence shall be avoided.

4.4.5 For the Class A special structures influenced by the seismic subsidence of soil or those under special requirements, their seismic measures of soil and foundation shall be determined after special study.

4.4.6 If soft soil layer and plastic loess with high moisture content exist within the scope of main bearing layer of soil, the pile foundation and soil strengthening or the measures specified in Article 4.3.9 of this code may be adopted through comprehensive consideration in combination of the specific conditions, or the corresponding measures may also be adopted according to the seismic subsidence amount of the soft soil.

4.5 Pile Foundations

4.5.1 The low-cap pile foundation mainly bearing the vertical loads may not be subjected to checking of vertical seismic bearing capacity and horizontal seismic bearing capacity of the pile foundation when the following conditions are followed simultaneously:

1 The requirements of Article 4.2.1 of this code are followed at Intensity 7 and Intensity 8.

2 No liquefaction soil layer or soft soil layer is available nearby the pile tip and pile body.

3 No liquefaction soil, mud, muddy soil, loosened sandy soil or filling with characteristic value of static bearing capacity less than 100kPa is available nearby the pile cap.

4 Non-slope section.

4.5.2 The seismic checking of low-cap pile foundation in non-liquefied soil shall meet the following requirements:

1 Both the characteristic values of vertical and horizontal seismic bearing capacity of individual pile may be increased by 25% than those of non-seismic design.

2 When the back filling soil surrounding the pile cap is tamped such that the dry density is not less than the requirements for filling as specified in the current national standard "Code for Design of Building Foundation" (GB 50007); the front filling of cap and the pile may together undertake the horizontal earthquake action; however, the frictional force between the bottom surface of cap and the soil shall not be taken into account.

4.5.3 The seismic checking of such low-cap pile foundation with liquefaction soil layer shall meet the following requirements:

1 If the cap is buried shallowly, the resistance of soil surrounding the cap and the

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5 Earthquake Action and Seismic Checking for Structures

5.1 General Requirement

5.1.1 Earthquake action calculation of special structures shall meet the following requirements:

1 Generally, the horizontal earthquake actions shall be calculated respectively along two main axis directions of the special structures construction unit and subjected to the seismic checking; the horizontal earthquake action in each direction shall be borne by the lateral-force-resisting components in this direction.

2 For the structures having the oblique lateral-force-resisting components, if the intersection angle is greater than 15°, the horizontal earthquake action along the direction of each lateral-force-resisting components shall be calculated respectively.

3 As for structures having obvious asymmetric mass and rigidity distribution, the torsion affects caused by horizontal earthquake actions in two directions shall be considered; for other structures, it is permitted to count in the torsion affects by adjusting the seismic action effect.

4 The vertical earthquake action shall be calculated for long span structure, long-cantilevered structure, hyperbolic cooling tower, Television tower, foundation of petrochemical tower-type equipment, blast furnace and ropeway at Intensity 8 and Intensity 9 and soar special structures such as headframe and shaft tower, boiler steel structure at Intensity 9.

5.1.2 The seismic calculation of various special structures shall adopt the following methods respectively:

1 The equivalent base shear method may be adopted for the frame-bent structures with mass and rigidity distributed uniformly along the height and the height not greater than 55m, other special structures with height not greater than 65m and the structure similar to the single-particle system. The mode-decomposition response spectrum method should be adopted for other structures.

2 The Class A special structures and extremely irregular special structures shall be subjected to supplemental calculation in time-history analysis method or the method determined by special study besides the mode-decomposition response spectrum method as required. The calculation result may take the average value in time-history analysis method or the larger value in mode-decomposition response spectrum method.

5.1.3 In case of time-history analysis method, at least two groups of real acceleration records at similar site conditions and one group of acceleration time-history curve for artificial earthquake on the matching design response spectrum shall be selected and the average seismic influence coefficient curve shall be consistent with the seismic influence coefficient curve adopted by mode-decomposition response spectrum method in the statistics. The base shear may be the average value of calculation result of

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2 As for the frame-walls set with a few seismic walls, if the seismic overturning moment bear by the bottom frame under the action of specified horizontal force is greater than 50% of the total seismic overturning moment of the structure, then the seismic grade of its frames shall be determined according to that of the frame structure and that of the seismic walls mat be identical to the seismic grade of these frames.

3 The frame (or frame-walls) with silos refer to the vertical wall set with longitudinal reinforced concrete silos, and the span-height ratio of vertical wall is no greater than 2.5; as for the vertical wall with the span-depth ratio greater than 2.5, it shall be determined according to ones without silos.

4 The large-span frame refers to the frame with span no less than 18m;

6.1.3 The plane and vertical layout, structural selection and material selection of frame-bent structures shall meet the following requirements:

1 In the structural unit plan, the layout of lateral-resisting components should be regular and symmetrical and the components should be set along the structure's full height and the lateral displacement stiffness of each colonnade in the structural unit should be uniform. The section dimensions of vertical lateral-force-resisting components should be dwindled away upwards and the abrupt change of lateral displacement stiffness and bearing capacity of lateral-resisting components should be avoided.

2 Equipment with great mass should not be arranged in the edge platform of structural unit, instead, it should be arranged in the position which is near structural stiffness center; if it is inevitable, equipment platform and main structure should be separated or low-level arrangement shall be adopted as far as possible when technological requirements are met.

3 The cantilever structure with heavy deadweight should not be adopted.

4 The enclosure wall should select light material, light wallboard and reinforced concrete wallboard etc. When the one end of structural unit is open and the other end is equipped with the gable, the gable shall be flexibly connected with the main structure.

6.1.4 Seismic joints of frame-bent structures shall meet the following requirements:

1 The seismic joint may be arranged where one of the following conditions occurs:

1) The building is built near to frame-bent structures;

2) The plan and vertical layout for the structure is irregular;

3) The abrupt change of mass and rigidity occurs along the longitudinal distribution.

2 The seismic joint on both sides shall be set with the bearing structure.

3 The equipment except for the belt conveyer and the link belt equipment shall not be set across the seismic joint.

4 The minimum width of the seismic joint shall meet the following requirements:

1) As for the close-built buildings and frame-bent structures, whose height is not greater than 15m, the width of the seismic joint shall not be less than 100mm at Intensities 6 and 7, and shall not be less than 110 mm at Intensities 8 and 9.

2) For frame-bent structure units (including frame-bent structures arranged with a few seismic walls), if the height of the building does not exceed 15m, the width of seismic joint shall not be less than 100mm; if not, the width, at Intensities 6, 7, 8 and 9 should be increased by 20mm respectively when the height is increased by 5m, 4m, 3m

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6.1.8 As for the roof, selection of the roof truss or roofing beam shall meet the following requirements:

1 The roof should adopt steel roof truss or the roof truss with prestressed concrete and reinforced concrete of lower gravity center.

2 Where the span is not greater than 15m, the reinforced concrete roofing beam may be adopted.

3 Where the span is greater than 24 m or at the Intensity 8 Class III and Class IV sites and at Intensity 9, the steel roof truss shall be adopted.

4 The roof truss of prestressed concrete or reinforced concrete should be not adopted for the roof with skylight truss outstanding the roofing.

5 At Intensity 8 (0.30g) and Intensity 9, the roof with span greater than 24m should not adopt the large roofing slab.

6.1.9 Type selection of the bent column in frame-bent structures shall meet the following requirements:

1 Different rectangular or I-shaped section columns or double-limb column with diagonal web component should be adopted instead of I-shaped column of thin wall, I-shaped column with open pore on web, I-shaped column of prefabricated web or pipe column.

2 When adopting the I-shaped column, within the range of above 500 mm from column bottom to indoor terrace and the upper column of stepped column and each column section at the corbel should adopt rectangular section.

3 The gable wind-resistant column may adopt the rectangular, I-shaped section reinforced concrete column or H-shaped steel column. When the bent-frame span is much higher, the gable wind-resistant beam should be arranged.

6.1.10 Layout of the steel ladder of upper and lower cranes shall meet the following requirements:

1 As for the structural unit, there is a gable in only one end, the steel ladder shall be set on the end close to gable.

2 As for the structural unit, a gable is in either end or no gable is in either end, the steel ladder shall be set in the middle.

3 When the unit is multi-span, the steel ladder shall be dispersedly set according to Items 1 and 2 of this article.

6.1.11 In the frame-bent structures, both the frames and the seismic walls shall be arranged in two directions, and the influence of the eccentricity shall be taken into consideration if the eccentricity between the center lines of the column and the seismic wall as well as between the center lines of beam and column is greater than 1/4 of the column width.

When the height of the frame part in the frame-bent structures is greater than 24m, the single-span frame structure should not be adopted.

6.1.12 As for the frame-walls, the length-width ratio of such floor slabs and roofs without large openings between their seismic walls should not be greater than those specified in Table 6.1.12; otherwise, the influence of the deformation in plan of the floor slab and roof shall be taken into consideration.

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structure, the influence of the stair components on earthquake action and effect shall be considered, and the seismic capacity for stair components shall be checked; the structural measures should be adopted to reduce the stair component influence on the main structure stiffness.

3 The infilled wall and column on the both sides of the staircase shall be connected and strengthened.

6.2 Essentials in Calculation

6.2.1 As for the irregular and higher frame-bent structures at Intensity 6 which is fabricated on Class IV site, and frame-bent structures at Intensities 7~9, the horizontal and vertical earthquake actions and seismic action effect shall be calculated according to that under of relevant frequent earthquakes as specified in Chapter 5 of this code.

6.2.2 As for the frame-bent structures, its earthquake action shall be calculated according to three-dimensional structural model and shall meet the following requirements:

1 The analysis for internal force and deformation of complex frame-bent structures under the frequent earthquake action shall adopt at least two different mechanical models, and the calculated results shall be analyzed and compared.

2 If the frame-bent structures are irregular, it shall meet the requirements of Articles 3.4.6 and 3.4.7 of this code.

3 During the seismic checking, the horizontal seismic shear-force for any storey of the structure shall comply with the requirements of Article 5.2.5 in this code.

4 When the skylight is arranged and is not counted in the calculation model of the frame-bent structures, the skylight mass may be focused on the roof truss or roofing beam at the lower part of the skylight truss in calculation of earthquake action.

5 As for the frame-bent structures with the silo, which transverse and longitudinal vertical walls are set, the stored-material loads shall be respectively distributed to longitudinal and transverse vertical walls. When there is only longitudinal vertical wall (the beam is transverse), the stored-material load shall be distributed to the longitudinal vertical wall.

6 If the vibration mode-decomposition response spectrum method for calculation is adopted, the number of the vibration mode should not be less than 12.

7 The calculated natural vibration period of the structure shall be multiplied by 0.8~0.9 of the cycle modified coefficient.

6.2.3 As for the structures having obvious asymmetric mass and stiffness distribution, its calculated earthquake action shall be counted in the torsion influence under the two-way horizontal earthquake action. The standard effect of the two-way horizontal earthquake action may be determined according to the larger value between the values in the Formula (5.2.3-1) and (5.2.3-2) of this code, where the torsion coupling effect under the tone-way horizontal earthquake action shall be determined according to the following formula:

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$\sum M_C$ -- the sum of design values of combined bending moment clockwise or counter clockwise on the upper and lower column end section of the joint, and the design value of bending moment for the upper and lower column end may be distributed according to the elasticity analysis;

$\sum M_b$ -- the sum of design values of combined bending moment clockwise or counter clockwise on the left and right beam end section of the joint, as for Grade 1 frames, bending moments of left and right beam end of the joint are hogging moments, the bending moment of the smaller absolute value between the two shall be taken as zero;

$\sum M_{bua}$ -- the sum of the actual bending moment values counterclockwise or clockwise on the right and left beam end section corresponding to the seismic flexural capacity of the normal section, which shall be determined according to the actual area of the rebar (including bearing reinforcements of the beam and rebars of related floor slabs) and the characteristic value of material strength;

η_c -- the amplified coefficient of the frame-column bending moment; as for the frame structure, it may take 1.7 for Grade 1, 1.5 for Grade 2, 1.3 for Grade 3, and 1.2 for Grade 4; as for the frame in the frame-seismic-wall, it may take 1.4 for Grade 1, 1.2 for Grade 2, 1.1 for Grade 3 and Grade 4;

3 If the inflection point is beyond the range of storey height for the column, the design value of the combined bending moment at column end section may be multiplied by such above-mentioned amplified coefficient of the column-end bending moment η_c.

6.2.8 As for the Grades 1, 2 and 3 frame beams and connecting beams of seismic walls, the design value of combined shear-force on the beam end section shall be modified according to the following formula:

$$V = \eta_{vb}(M_b^l + M_b^r)/l_n + V_{Gb} \tag{6.2.8}$$

Where:

V -- the design value of combined shear-force at the beam end section;

η_{vb} -- the amplified coefficient of shear-force foe beam end, it may be taken as 1.3 for Grade, 1.2 for Grade 2 and 1.1 for Grade 3;

l -- the span of the beam;

V_{Gb} -- the design value of section shear-force at the beam end when the beam under the action of the representative value of gravity load is analyzed by simply-supported beam;

M_b^l, M_b^r -- respectively the design values of counterclockwise or clockwise combined bending moment on the right and left beam ends. As for the Grade 1 frame, if values of the frame on both ends are negative bending moment, the bending moment with smaller absolute value shall be taken as zero.

6.2.9 As for Grade 1 frame structure as well as the Grade 1 frame beam and connecting beam at Intensity 9, the design value of combined bending moment for the end section may not be modified according to the above formula, but shall meet the requirements of the following formula:

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Where:

V -- the design value of combined shear-force on the section of reinforced bottom part of the seismic wall;

η_{vw} -- the amplified coefficient for seismic wall's shear-force, which may be taken as 1.6 for Grade 1, 1.4 for Grade 2 and 1.2 for Grade 3;

V_w -- the calculated value of combined shear-force on the section of reinforced bottom part of the seismic wall.

6.2.14 As for the Grade 1 seismic wall of Intensity 9, the design value of combined shear-force on the section of reinforced bottom part may not be modified according to this formula (6.2.13), but shall meet the requirements of the following formula:

$$V = 1.1\frac{M_{wua}}{M_w}V_w \tag{6.2.14}$$

Where:

M_{wua} -- the bending moment on the bottom section of seismic wall corresponding to the seismic flexural capacity, is calculated according to the actual area of longitudinal rebars, the characteristic value of material strength and axial force; if there is any wing wall, the longitudinal rebar within the a range of one time of the wing wall's thickness on either side of the wall shall be taken into account;

M_w -- the design value of combined bending moment on the bottom section of seismic wall.

6.2.15 For seismic walls, the design values of the combined internal force of each wall limb section shall be adopted according to the following requirements:

1 At parts above the reinforced bottom part of Grade 1 seismic wall, the design value of combined bending moment of wall limbs shall be multiplied by an amplified coefficient, and the value hereof may be taken as 1.2 and be correspondingly modified.

2 In the coupled seismic wall, the wall limbs should be free from light eccentric-tension; if any wall limb is eccentrically tensed, the design values of the shear-force and bending moment of the other wall limb shall be multiplied by an amplified coefficient of 1.25.

6.2.16 As for beams, columns, seismic walls and coupling beams of the reinforced concrete structures, the design values of the combined shear-force on the section hereof shall meet the following requirements:

1 Beams and coupling beams with span-depth ratio greater than 2.5, as well as the columns and seismic walls with shear-span ratio greater than 2 shall meet the requirements of the following formula:

$$V \le \frac{1}{\gamma_{RE}}(0.20 f_c b h_0) \tag{6.2.16-1}$$

2 Coupling beams with span-depth ratio not greater than 2.5, columns and seismic walls with shear-span ratio not greater than 2, frame columns of the supporting silo vertical wall as well as the reinforced bottom parts of floor-type seismic walls shall meet the requirements of the following formula:

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$$V = \frac{1}{\gamma_{RE}}(0.15 f_c b h_0) \quad (6.2.16\text{-}2)$$

3 The shear-span ratio shall be calculated according to the following formula:

$$\lambda = M^c/(V^c h_0) \quad (6.2.16\text{-}3)$$

Where:

λ -- the shear-span ratio, which shall be determined according to the calculated value M^c of the combined bending moment on the column-end or wall-end section, the calculated value V^c of the combined shear-force on the corresponding section and the effective height h_0 of this section, and the greater value of calculated results for the upper and lower ends shall be taken; as for the frame column with the inflection point located at the middle of column height, it may be calculated according to the ratio between clear height of column and twice of the column's sectional height;

V -- the design value of combined shear-force on the section of beam end, column end or wall end, which is modified according to those specified in Articles 6.2.8 ~ 6.2.14 of this code;

f_c -- the design value of axial compressive strength of concrete;

b -- the section width of the beam and column or width of the wall limb's section for seismic wall;

h_0 -- the effective height of the section, for the seismic wall, the effective height may adopt the length of wall limb section.

6.2.17 The seismic calculation of frame-bent structures shall meet the following requirements:

1 As for the frame-seismic-wall structure with basically uniform distribution of lateral displacement stiffness along the vertical direction, the seismic shear-force on the frame part for each storey shall not be less than the smaller value between 20% of the total seismic shear-force at the bottom of the structure and 1.5 times the maximum value among the seismic shear-force of each storey in the frame part.

2 To calculate the seismic internal force of seismic wall, the coupling beam's stiffness may be reduced and the reduction coefficient should not be less than 0.5.

3 As for the frame structure arranged with less seismic wall, the seismic shear-force value of frame part hereof should adopt the larger one of the calculated results between the frame structure model and frames-wall structure model.

4 To calculate the internal force and deformation of the frame-seismic-wall structure, its seismic wall shall be counted in joint action of the end wing wall.

6.2.18 The seismic checking of the frame joint core area shall meet the following requirements:

1 The joint core areas of the Grades 1, 2 and 3 frames shall be subjected to seismic checking; the joint core areas of Grade 4 frames may not be subjected to seismic checking, but shall meet the requirements of the details of seismic design.

2 The method for checking for strength of core zone shall comply with those specified in Appendix D of this code.

6.2.19 At Intensity 7 (0.15 g) Class III and Class IV sites and Intensities 8 and 9, tensile and compressive effects generated by transverse seismic effect shall be

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requirements:

1 The longitudinal rebar of the column should be symmetrical.

2 For the column with sectional side length greater than 400 mm, the spacing of longitudinal rebar should not be greater than 200 mm.

3 The total reinforcement ratio of the column shall not be greater than 5%.

4 As for the Grade 1 frame, if the shear-span ratio of the column is not greater than 2, the ratio of reinforcement of longitudinal rebar on each side of column should not be greater than 1.2%.

5 When the frame column, side column and corner column of the supporting silo vertical wall and end column of the seismic wall are eccentrically tensed, the gross sectional area of the longitudinal rebar in the column shall be increased by 25% than the calculated value.

6 The tied joint of column's longitudinal rebar shall avoid the stirrup densified area of the column end.

6.3.9 The densified range of the column stirrup shall be adopted in accordance with the following requirements:

1 As for upper and lower column ends, the maximum value among the sectional height, 1/6 of column's clear height and 500mm shall be taken.

2 The lower end of the bottom column shall not be less than 1/3 of the column's clear height. When there is rigid ground, each 500mm shall be taken for the upper and lower part of the rigid ground, except for the column end.

3 As for the columns with shear-span ratio not greater than 2 and the columns whose ratio of clear height and column section height is not greater than 4 and is formed by infilled walls, they shall be taken the full height.

4 The corbel shall be set in the column segment; as for the upper and lower column segments in the corbel, whose ratio between the clear height and sectional height is not greater than 4, they shall be taken full height; if not, each 500mm shall be taken for the column segment end.

5 For frame columns of supporting silo vertical wall and corner columns of Grades 1, 2 frames, they shall be taken full height.

6.3.10 As for the spacing of stirrup legs in the column densified area should not be greater than 200mm; it should not be greater than 200mm for Grade 1, should not be greater than 250 mm for Grades 2 and 3, and should not be greater than 300mm for Grade 4. At least, the stirrup or the tie bar shall be set to restrain every other longitudinal rebar in two directions. When adopting the tie bar compound stirrup, the tie bar should be abutted against the longitudinal rebar, grapple the stirrup and shall meet the requirement for the spacing of stirrup legs.

6.3.11 The stirrup ratio per unit volume of the column stirrup in the densified area shall meet the requirements of the following formula:

$$\rho_v \geq \lambda_v f_c / f_{yv} \tag{6.3.11}$$

Where:

ρ_v -- the stirrup ratio per unit volume of column stirrup in the densified area, it shall not be less than 0.8 % for Grade 1, shall not be less than 0.6 % for Grade 2 and shall not be less than 0.4 % for Grades 3 and 4;

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7 Steel Frame-bent Structure

7.1 General Requirement

7.1.1 This Chapter is applicable to the seismic design of the frame-bent structures which are composed of composite steel frame, composite steel frame-bracing and single-layer steel bent-frame.

7.1.2 The skylight truss of steel frame-bent structures outreaching the roofing should adopt the rigid frame or truss structure. The end wall and wind screen of the skylight should be made of light materials. At Intensities of 8 and 9, the bent-frame longitudinal skylight truss should be arranged from the second column bay at the structural unit end; if not, the partial upper transverse bracing shall be added for the roof of the first bay in which the skylight truss is arranged. The distance from starting point of the transverse skylight truss to roof truss end should not be less than 4.5m.

7.1.3 A complete roof bracing system and inter-column bracing shall be arranged for the frame-bent structures.

7.1.4 Cast-in-situ slab should be adopted for the floor (roofing) slab of frames; the reinforcement cast-in-situ layer should be arranged for the precast slab. Partial floor system horizontal bracing shall be arranged for the floor slab whose pores are relatively large.

7.1.5 Enclosing materials of roofing and wall space for the frame-bent structures should be light slabs. The arrangement of the enclosure wall and non-bearing inner wall of the frame-bent structures shall meet the following requirements:

1 If the masonry wall is adopted, the flexible connection which doesn't restraint deformation of the frame-bent major structure should be adopted for the connection between the wall and frame-bent structures. If not, both earthquake action calculation and seismic checking of structure components shall be counted as its adverse influence.

2 When masonry filling wall of the frame inflexibly connects with frame column, its plane and vertical layout should be symmetrical, uniform, continuous up and down.

7.1.6 Larger chimney and bleeder which is supported on the floor (roofing) and outreaches the roofing, should be regarded as a part of the structure for the integral structure calculation under earthquake action; details of seismic design shall be taken for the connecting parts of structures.

7.1.7 The seismic joint may not be arranged for the frame-bent structures once they adopt a regular structural scheme, if it is necessary to arrange seismic joint, its width shall not be less than 1.5 times the corresponding reinforced concrete structure.

7.2 Essentials in Calculation

7.2.1 The seismic influence coefficient of frame-bent structures shall be determined in accordance with that under frequent earthquakes as specified in Chapter 5 of this code; The calculation of horizontal earthquake action and action effect shall be carried out.

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model shall meet the following requirements:

1 For the solid web column, it shall be counted in bending deformation; as for $H_a/h \leq 4$ short column (H_a is column's clear height; h is the column sectional height along the checking plane), it shall be counted in shear deformation. The solid web beam shall be counted in bending deformation; as for $l_a/h \leq 4$ short beam (l_a is the beam's clear span length, h is the girder's section height), it shall be counted in shear deformation.

2 The sectional moment of inertia of the frame beam may be calculated according to the following requirements:

1) When the floor slab is a steel planking, the steel beam sectional moment of inertia I_G may be directly adopted;

2) Two I_G may be adopted for the frame girder once the floor slab is the concrete cast-in-situ layer arranged on the profiled steel plate and have reliable connection with the frame beam.

3) For the steel-concrete combined floor system, I_c the moment of inertia of the beam-slab combined section may be adopted; the minimum value in the following formula may be adopted for the effective width of the cast-in-situ concrete slab:

$$b_e = l/3 \tag{7.2.3-1}$$

$$b_e = b_0 + 12h_c \tag{7.2.3-2}$$

$$b_e = b_0 + b_1 + b_2 \tag{7.2.3-3}$$

Where:

b_e -- the effective width of the cast-in-situ concrete slab;

l -- the span of the steel beam;

b_0 -- the width of the top flange for steel beam;

h_c -- the thickness of the concrete slab;

b_1, b_2 -- respectively 1/2 the clear spacing between the adjacent steel beams on either side and they shall not be greater than actually outreaching width of the concrete slab.

3 The deformation of bracing members and calculation of stiffness may be adopted according to the requirements of Appendix F in this code.

7.2.4 In the analyzing of the bent, the calculated length of the column may be adopted according to the following requirements:

1 In the hinging the roof truss and the bent-frame column, the length may be taken up to the chapiter.

2 In the rigidly connecting the roof truss and the bent-frame column, the length may be taken up to axial line of the lower chord for the roof truss.

7.3 Modification of Seismic Action Effect on Structure

7.3.1 In the seismic checking of the longitudinal bracing for the skylight truss extruding the roofing, the seismic action effect of its skylight truss shall be multiplied by the effect amplified coefficient once the earthquake action is calculated by equivalent base shearing method; the calculation of the effect amplified coefficient shall meet the following requirements:

1 As for vertical bracing on either side of the skylight truss, which is on the top of

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A_{f1}, A_{f2} -- respectively the area of bottom flange section for the *AB* and *BC* segment in the haunching zone;

β_1 -- the included angle between the *AB* segment in the haunching zone and rigid-frame beam axis;

β_2 -- the included angle between the *BC* segment in haunching zone and rigid-frame column axis;

θ -- the included angle between the diagonal stiffener and horizontal plane;

f_y -- the tensile-compressive yield strength of the lower flange plate steels in the haunching zone;

f_y^d -- the tensile-compressive yield strength of diagonal stiffener steels;

γ -- the included angle between the rigid frame beam axis (or top flange) and horizontal plane;

A_f -- the area of top flange plate section in the haunching zone; generally, it may be is the same as rigid-frame beam top flange;

f_{vy} -- the shear-resistant yield strength of web plate in the haunching zone;

h_{EB} -- the calculation height of horizontal section at Point *B* in the haunching zone; it may be taken as horizontal distance between the outer and inner flange plates' central lines.

7.5 Seismic Checking for Connections of Structural Components

7.5.1 At Intensities 7~9, the welding, the connection of the friction-type high-strength bolts or mixed bolt-welding connection may be adopted for connections between the main components and joints of frame-bent structures. In adopting welding, the full-welded connection shall be adopted for the butt connection of the frame joint panel.

7.5.2 At Intensities 7~9, seismic checking of joint connection for frame-bent structure components shall meet the following requirements:

1 For the following main joints with potential plastic hinge, they shall be designed according to the maximum bearing capacity of joint connection which shall not be less than the plastic bearing capacity of components:

1) Connecting joints between the frame beam and the column;

2) Inter-column bracings and connecting joints of frame-bent;

3) Important rigid connection joints between the multi-layer frame/bent-frame column and foundation.

2 For the main component splicing to transmit or bear earthquake action, its bearing capacity shall not be less than 1.1 times the action effect value at this part once it is not in the component plastic area; simultaneously, the bending bearing capacity of the splicing between the beam and column still shall not be less than 0.5 $W_e f_y$, , W_e and f_y are respectively the elastic section modulus and steels yield strength of the beam column section.

7.5.3 For the fillet weld connection, the incompletely-penetrated butt connection or friction-type high-strength bolt connection of the following component joint, the elastic design shall be carried out in accordance with the seismic combined internal force and

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8 Steel Structures for Boilers

8.1 General Requirement

8.1.1 This Chapter is applicable to the seismic design of supporting-type and hanging boiler steel structures.

8.1.2 Boiler steel structures for thermal power plants, with the single machine capacity of 300MW or above or the planned capacity of 800MW or above shall belong to Class B special structures, and those with the single machine capacity of 300MW or below or the planned capacity of 800MW or below shall belong to Class C special structures.

8.1.3 The boiler steel structure should be an independent structure. The plant built closely to the boiler steel structure shall be arranged with seismic joints, and the width of the seismic joint shall be 1.5 times the width of the seismic joint of reinforced concrete structure.

8.1.4 The supporting-type boiler equipped with heavy boiler wall or light boiler wall with metal-framed guard plate should be the frame-type boiler steel structure with column and beam in rigid connection. If the guard plate and the column beam are connected with the built-in mode at the area arranged with metal-framed guard plates, the beam, column and guard plate may be regarded as a rigid plane structure.

8.1.5 The hanging boiler steel structure may adopt the intermediate support system for which the X-shaped, single diagonal-shaped, lambdoidal and V-shaped bracings shall be selected, not the K-shaped bracing. At Class III and Class IV sites of Intensity B and at the site of Intensity 9, the boiler steel structure should adopt the eccentric bracing system.

8.1.6 When the intermediate support system is designed in consideration of the draw bar, two groups of single diagonals with different vergence directions shall be simultaneously arranged, and the difference between projected areas of sectional areas of single diagonals in different directions in each group along the horizontal direction shall not be greater than 10%.

8.1.7 The boiler steel structure shall be arranged with vertical bracing systems in the vertical plane with greater load, and vertical bracings shall be arranged uniformly and continuously along the height of the boiler steel structure.

8.1.8 The boiler steel structure shall be arranged with horizontal bracings in the horizontal plane with greater load, and a continuous enclosed bracing system should be made around the boiler steel structure. One layer of horizontal bracings should be arranged along the height of the boiler steel structure every other 12~15m, and their elevations shall be consistent with those of the boiler guiding device, and the horizontal earthquake action of the boiler body shall be able to be transmitted to the vertical bracing through the horizontal bracing.

8.1.9 The seismic calculation of the boiler steel structure may not take the mutual influence of the soil and the structure into account.

8.1.10 The roof structure at the boiler top and the closefitting enclosure should both adopt the light steel structure.

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9 Silo

9.1 General Requirement

9.1.1 This Chapter is applicable to the seismic design of the reinforced concrete, steel and masonry silos for storing bulk materials.

9.1.2 The silo appearance should be simple and regular, with its mass and stiffness evenly and symmetrically distributed; at Intensities 6 and 7, the sieving room with the silo wall extending upward and thus serving as the bearing structure or the framed sieving room may be adopted at the silo top; at Intensities 8 and 9, the sieving room with the silo wall extending upward and thus serving as the bearing structure shall be adopted at the silo top where the sieving room of other bearing structures shall not be arranged.

9.1.3 The silo structure shall be such selected to meet the requirements below:

1 The reinforced concrete silo may adopt the structural form supported by the silo wall, column and silo wall with pilaster, and jointly by the silo wall and column, and the silo wall supporting structure should be selected in priority. The deep silo with the diameter not less than 15m should adopt the structural form supported jointly by the silo wall and inner column, and the pilaster should be arranged at the silo wall opening. The cylinder silo with the diameter not less than 18m should adopt the structural form arranged independently.

2 The support column beneath the reinforced concrete column-bearing rectangular silo shall stretch to the silo top or buildings on the silo, and shall be integrally connected with the silo wall.

3 The steel silo may adopt the steel or cast-in-situ reinforced concrete silo bottom and the steel supporting structure beneath the silo; the silo wall floor-type structure should be adopted when the diameter hereof is greater than 12m; silo groups should be arranged in multiple rows.

4 At Intensities 6 and 7, the masonry silo with the diameter not greater than 8m and wall supporting structure being adopted may be adopted.

5 In addition to meeting those required for the seismic joint, the clear distance between independent silos shall also meet the requirements for construction and installation etc.

9.1.4 Buildings on the silo, except the sieving room, shall meet the requirements below:

1 Buildings on the silo should be made with steel structures, and its enclosure shall be made with light materials.

2 Buildings on the silo made with reinforced concrete structures may be used for the reinforced concrete silo and the masonry silo, and the enclosure hereof should be made with light materials.

3 At Intensity 6, buildings on the reinforced concrete silo and masonry silo may adopt masonry structures.

4 Roofs of the buildings on the silo should adopt steel light structures or

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cast-in-situ reinforced concrete structures.

9.1.5 The seismic joint of the silo shall be such arranged to meet the requirements below:

1 If sieving rooms are arranged partially on tops of reinforced concrete group silos, seismic joints shall be arranged at the space formed due to altitude difference.

2 Seismic joints shall be arranged at the place where the silo is adjacent to the auxiliary building.

3 For group silos or row-by-row silos with greater altitude difference or arranged irregularly, seismic joints shall be arranged at their corresponding positions.

4 The width of the seismic joint should be determined according to the relative deformation analysis result of the structure, but its minimum width shall not be less than 50mm.

9.1.6 Foundations of column-bearing silos in Class III and IV sites should be ring foundations or complete foundations, and measures to increase the integrity and stiffness of the foundation shall be taken.

9.1.7 Measures to reduce stress concentration shall be taken at the position where rigidities of structural components of the silo vary.

9.1.8 Degrees of indeterminacy should be increased for the supporting structure of the column-bearing silo. When redundant component bars and bracings are increased, its components shall also be possessed of good deformability in addition to meeting the strength requirements.

9.1.9 Independent silos in Class III and IV sites and under heterogeneous foundation condition shall be provided with measures to resist overturning and control differential settlement. Liquefaction soils shall all be provided with measures to eliminate liquefaction settlement.

9.1.10 The seismic precautionary category of the silo shall be determined according to its vitality in the production system and its secondary disaster degree possibly caused in the earthquake. If not specially required, the silo may be subjected to the seismic design as that for Class C special structure.

9.1.11 The same structural unit of the silo shall adopt the foundation of the same type. Foundations of the same structural unit should be arranged at the same elevation, if not, measures to prevent differential settlement of the soil shall be taken.

9.1.12 At Intensities 8 and 9, the silo structure may be provided with measures to dissipate energy and absorb the shock.

9.2 Essentials in Calculation

9.2.1 As for the silo, its seismic influence coefficient shall be determined according to that under frequent earthquakes as specified in Chapter 5 of this code, and the earthquake action and the action effect shall also be calculated.

9.2.2 The horizontal earthquake action of the silo may be calculated with the mode-decomposition response spectrum method or equivalent base shear method; when the silo structure is irregular and possessed of obvious weak positions in Class III and IV sites at Intensity 8, and at Intensity 9, the time-history analysis method should

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4 When the side length of the hole mouth is less than 1m, additional rebars at each side of the hole mouth shall not be less than 2Φ16 in sectional area, and 60% of the cut-off rebar at the hole mouth in sectional area; sectional areas of diagonal rebars at four corners of the hole mouth shall not be less than 2Φ16; when the side length of the hole mouth is not less than 1m, strengthening frames shall be arranged around the hole mouth; the reinforcement amount at each side of the strengthening frame shall not be less than 60% of the sectional area of the cut-off rebar at hole mouth, and diagonal rebars shall also be arranged at four corners of the strengthening frame.

5 When the opening width of the supporting silo wall is greater than or equal to 3m, the reinforcement shall be carried out according to the actual distribution condition of the stress of the silo wall. If the pilaster is arranged at both sides of the hole mouth, its sectional area should not be less than 400mm×600mm, and its head shall stretch into the silo wall; reinforcement for the pilaster shall be carried out according to the construction requirements for the pilaster, and the total reinforcement ratio should not be less than 0.6%.

6 The width of silo wall between adjacent hole mouths shall not be less than 3 times the wall thickness, and not be less than 500mm; when the silo wall width is 3~5 times the wall thickness, reinforcement shall be carried out according to those specified for the support column, and the reinforcement ratio hereof shall be determined through calculation and meet corresponding requirements for seismic design.

7 When the silo bottom and silo wall are connected non-integrally, the horizontal rebar at the silo wall bottom shall stretch into the silo wall beneath the top surface of the silo bottom structure, and the stretching-in height shall not be less than 6 times the silo wall thickness.

9.3.8 The masonry silo shall meet the requirements below:

1 Both the silo wall and the supporting silo wall shall be arranged with cast-in-situ reinforced concrete ring beam and structural column. The spacing to arrange ring beams shall be determined through calculation along the silo wall height; the ring beam spacing should not be greater than 2m at the silo wall and 3m at the supporting silo wall, and one streak of ring beam shall be arranged respectively at the silo top and bottom; the structural column spacing should not be greater than 3.5m.

2 The section width of the reinforced concrete ring beam shall be identical to the wall thickness, and its height shall not be less than 180mm; the specification for longitudinal rebar should not be less than 4Φ12 and the stirrup spacing should not be greater than 250mm; the section of the structural column shall not be less than the wall thickness, the specification for longitudinal rebar should not be less than 4Φ14, and the stirrup spacing shall not be greater than 200mm; stirrups at upper and lower ends of the column should be properly densified, and rebars not less than 2Φ6 shall be arranged along the column height every other 500mm to be tied with silo wall or supporting silo wall masonry, and the tying length stretching into the masonry at each side should not be less than 1m.

3 The silo wall thickness shall be determined through calculation, and not less than 240mm, and the thickness of the supporting silo wall shall not be less than 370mm; if the thickness of the silo wall is unequal to that of the supporting silo wall, the inner

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10.2 Essentials in Calculation

10.2.1 As for the headframe, its seismic influence coefficient shall be determined according to that under frequent earthquakes as specified in Chapter 5 of this code, and the earthquake action and action effect shall then be calculated.

10.2.2 The headframe shall be subjected to horizontal earthquake action calculation respectively along main shaft directions longitudinally parallel to the hoisting plane and transversely vertical to the hoisting plane. The headframe meeting any of the following requirements may not be subjected to seismic checking, but shall meet corresponding requirements for seismic measures:

1 The longitudinal horizontal earthquake action of the four-column reinforced concrete headframe at Intensities 7 and 8.

2 The longitudinal horizontal earthquake action of the six-column reinforced concrete headframe at Intensity 7.

3 The steel headframe at Intensity 7.

10.2.3 The damping ratio of the reinforced concrete headframe may be 0.05; the damping ratio of the steel headframe may be 0.03 under frequent earthquakes and 0.04 under rare earthquake.

10.2.4 The mode-decomposition response spectrum method should be adopted as required for the multi-particle space-bar system model to carry out seismic calculation of the headframe. The seismic calculation for four-column reinforced concrete headframe may be carried out with the equivalent base shear method. For the double-braced steel headframe with the stand and diagonal bracing being disconnected, the diagonal bracing and the stand shall respectively be subjected to seismic calculation. For the steel headframe higher than 60m and at Intensity 9, the time-history analysis method should be adopted to carry out supplemental calculation under frequent earthquakes and such calculation shall also meet those specified in 5.1.3 and 5.1.7 etc. of this code.

10.2.5 For the adoption of mode-decomposition response spectrum method, at least 9 vibration modes shall be taken for the reinforced concrete headframe and at least 15 vibration modes for the steel headframe.

10.2.6 If the equivalent base shear method is adopted to calculate the fundamental period of the four-column reinforced concrete headframe, the following formulae may be referred to:

$$T_y = -0.0406+0.0424H/\sqrt{l_n} \tag{10.2.6-1}$$

$$T_x = -0.1326+0.0507\sqrt{H(l_a+l_b)} \tag{10.2.6-2}$$

Where,

T_y -- the longitudinal fundamental period (s) of the headframe;

T_x -- the transverse fundamental period (s) of the headframe;

H -- the headframe height, which may be the vertical distance (m) from the shaft

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3 The design value of combined shear-force on the end section of the frame beam shall be adjusted according to the formula below:

$$V = \eta_{vb}(M_b^l + M_b^r)/l_n + V_{Gb} \quad (10.2.11\text{-}1)$$

Where,

V -- the design value of combined shear-force on the beam end section;

l_n -- the clear span of the beam;

V_{Gb} -- the design value of combined shear-force on the beam end section under the action of the representative value of gravity load of the beam (at Intensity 9, the characteristic value of the vertical earthquake action shall also be included), which is analyzed according to that for simple-supported beam;

M_b^l and M_b^r -- the design values of combined bending moment clockwise or counterclockwise on the right and left end sections of the beam;

η_{vb} -- the amplified coefficient for shear-force at the beam end, which shall respectively be 1.3, 1.2 and 1.1 at Grades 1, 2 and 3.

4 The design value of combined shear-force on the end section of the frame column shall be adjusted according to the formula below:

$$V = \eta_{vc}(M_c^b + M_c^t)/h_n \quad (10.2.11\text{-}2)$$

Where,

V -- the design value of combined shear-force on column end section;

h_n -- the net height of the column;

M_c^t and M_c^b -- the design values of combined bending moment clockwise or counterclockwise on upper and lower end sections of the column, which shall also be multiplied by amplified coefficients according to Item 1 and Item 2 of this article;

η_{vc} -- the amplified coefficient for shear-force at the column end, which shall respectively be 1.4, 1.2 and 1.1 at Grades 1, 2 and 3.

10.2.12 For the reinforced concrete headframes of Grades 1 and 2, the frame column-beam joint core zone shall be subjected to section seismic checking according to Appendix D of this code.

10.2.13 In addition to having been adjusted according to 10.2.11 of this code, the design value of combined bending moment and combined shear-force on the corner column section of the reinforced concrete headframe shall also be multiplied by the amplified coefficient not less than 1.1.

10.2.14 When the steel headframe is subjected to internal force and deformation analysis under horizontal earthquake action, the gravity second-order effect influence shall be counted in according to 3.5.3 of this code.

10.2.15 In addition to meeting those specified in 5.4.2 of this code, the section seismic checking for headframe structural component shall also meet the requirements below:

1 The modified coefficient of seismic bearing capacity for the reinforced concrete headframe shall be 0.75 for the beam, 0.75 for the upright column when

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greater than 3.

10.3.6 The axial compression ratio of the headframe column should meet those specified in 6.3.6 of this code.

10.3.7 In addition to meeting those specified in 6.3 of this code, the reinforcement for the headframe column shall also meet the requirements below:

1 The reinforcement ratio of the longitudinal rebar at each side shall not be less than 0.3%.

2 The length of the stirrup densified area of the stand bottom column shall be the full height of the column.

10.3.8 The beam structure equipped with diagonal bracing should be adopted for the supporting beam of the hoisting sheave beam.

10.4 Details for Steel Headframe

10.4.1 Components of the steel headframe shall be welded or connected through high-strength bolt connection.

10.4.2 The slenderness ratio of the primary components of the steel headframe shall meet the requirements below:

1 The slenderness ratio of the bracing column, stand column and compression bar of the supporting structure for hoisting sheave shall not be greater than $120\sqrt{235/f_y}$ at Intensity 8, and $100\sqrt{235/f_y}$ at Intensity 9; f_y is the yield strength or yield point of steels.

2 The slenderness ratio of the compressive web component in the diagonal bracing and stand shall not be greater than $120\sqrt{235/f_y}$.

3 The slenderness ratio of the tensile web component in the diagonal bracing and stand shall not be greater than $100\sqrt{235/f_y}$.

10.4.3 Main stressed components of the steel headframe shall meet the requirements below:

1 For components like hoisting sheave supporting structure, cage-supporting beam, bumper beam, stand column and bracing column etc., the minimum thickness of their steel plates shall not be less than 8mm.

2 The section steel component shall meet the requirements for minimum section; the angle steel shall be ∟63×6, the I-shaped steel shall be I14, the channel steel shall be [12.6, and the height of hot-rolled H-shaped section steel shall be 150mm.

3 The thickness of joint plate shall not be less than 8mm.

10.4.4 The structure of diagonal bracing shall meet the requirements below:

1 The foundation bolt shall be the double-nut bolt equipped with rigid anchor plate (or anchor beam).

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method. The adoption of time-history analysis method shall meet those specified in 5.1.3 and 5.1.7 of this code.

11.2.7 For the adoption of mode-decomposition response spectrum method, at least 9 vibration modes shall be taken for the reinforced concrete shaft tower and at least 15 vibration modes for the steel shaft tower.

11.2.8 During the earthquake action calculation, the representative value of the gravity load for shaft tower shall be adopted according to the requirements below:

1 Representative values of gravity loads for the structure, devices placed on the floor, stocks fixed to the shaft tower and various rigid guides etc. shall be 100% of the characteristic deadweight values.

2 The combined value coefficient of variable load for the flooring shall be 1.0 when calculated according to the actual condition, and 0.5 when calculated according to the equivalent uniformly-distributed load.

3 The combined value coefficient of roofing snow load shall be 0.5.

4 The combined value coefficient of stored-material load in the ore silo shall be 0.8 obtained when the silo is fully stored with materials.

11.2.9 At Intensity 9, the shaft tower shall be subjected to vertical earthquake action calculation, and the adverse combination shall also be carried out through calculation of vertical earthquake action and horizontal earthquake action.

11.2.10 The vertical seismic action effect of shaft tower shall be calculated according to the requirements specified in 5.3.1 of this code, and it shall be multiplied by the amplified coefficient 2.5.

11.2.11 When structural components of the shaft tower are subjected to section seismic checking, the fundamental combination of the seismic action effect and other load effects shall meet those specified in 10.2.10 of this code.

11.2.12 For the reinforced concrete tube-frame structural shaft tower under the horizontal earthquake action, the total seismic shear-force borne by the frame column at any layer beneath the winder hall shall not be less than the smaller one between the value being 20% of the total seismic shear-force for the ground layer of the shaft tower and the value being 1.5 times the maximum seismic shear-force at such layer for the frame structures calculated as the value for the tube-frame structure. The shear-force of each column at this layer, bending moments for upper and lower column ends, bending moments and shear-forces for both ends of the frame column connected with the column at this layer shall all be properly adjusted with the same proportion.

11.2.13 For the steel-frame-bracing structural shaft tower under the horizontal earthquake action, the total seismic shear-force borne by the frame column at any layer beneath the winder hall shall not be less than the smaller one between the value being 25% of the total seismic shear-force for the ground layer of the shaft tower and the value being 1.8 times the maximum seismic shear-force at such layer for the frame structures. The shear-force of each column at this layer, bending moments for upper and lower column ends, bending moments and shear-forces for both ends of the frame column connected with the column at this layer shall all be properly adjusted with the same proportion.

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1.4.

11.3 Details for Reinforced Concrete Shaft Tower

11.3.1 Details of seismic design for the reinforced concrete frame and the frame of the tube-frame structural shaft tower shall comply with the relevant requirements of 6.3 in this code.

11.3.2 The tube wall of the reinforced concrete tube-structured shaft tower should meet the following requirements:

1 The tube wall thickness shall not be less than 200mm. When the tube wall thickness at each layer is not equal, the tube wall thickness difference between adjacent layers should not exceed 1/3 of the smaller tube wall thickness.

2 The tube wall shall be adopted with the double-layer reinforcement, the diameter of vertical rebar should not be less than 12mm, and the spacing shall not be greater than 250 mm; the diameter of transverse rebar should not be less than 8mm, and the spacing shall not be greater than 250mm; diameters of the vertical and transverse rebars should not be greater than 1/10 of the tube wall thickness, the transverse rebar should be arranged outside of the vertical rebar; as for the tie bar between the rebars in double layers, the spacing should not be greater than 500mm, and the diameter shall not be less than 6mm; as for the vertical and transverse rebars for the tube wall, their reinforcement ratios shall not be less than 0.25 %.

3 The splay angle with the width not less than the tube wall thickness and not less than 250mm, and the corner column may be arranged inside the place where four corners of the tube wall for rectangular-plane shaft tower are connected; the position where the splay angle is located or the corner column shall be arranged with longitudinal rebar and stirrup as required for the column; in addition to meeting the calculation requirements, the rebar area shall also meet the requirements of 6.4.7 in this code.

4 When the height or width of the hole mouth for tube wall is not greater than 800mm, the area of reinforced rebar at each side of the hole mouth shall not be less than 1/2 of the area of rebar cut by the hole mouth, and shall not be less than 2Φ14; the anchorage length of the rebar shall not be less than l_{aE}, and the l_{aE} shall be 1.15l_a for seismic grades 1 and 2, 1.05l_a for seismic grade 3, and shall not be less than 600mm.

5 When the height or width of hole mouth for tube wall is greater than 800mm, the edge components shall be arranged at both sides of the hole mouth as required in 6.4 of this code, the connecting beam should be arranged above or beneath the hole mouth.

6 When the width of the hole mouth for the tube wall is greater than 4m or 1/3 of the width of the tube wall at the corresponding structure, the reinforced rib shall be arranged at both sides of the hole mouth, the reinforced rib shall be throughout the whole layer. The connecting beam shall be arranged at the upper part of the hole mouth, or at the lower part of the hole mouth if the hole mouth is not at the shaft tower bottom. The reinforced rib shall be arranged with the longitudinal rebar and stirrup according to the requirements of the frame column; the area of the rebar shall not only comply with

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coefficient being counted;

γ_w and γ_t -- respectively the partial coefficient of wind load and temperature action, in which that for the wind load shall be 1.4 and that for the temperature action shall be 1.0;

ψ_w and ψ_t -- respectively the combination value coefficient of wind load and temperature action, in which that for the wind load shall be 0.25, and that for the temperature action shall be 0.6.

12.2.8 The interaction between the soil and the upper structure should be counted in the earthquake action calculation of tower tube structure, and the dynamic parameter of earth shall be adopted in such calculation.

12.2.9 The soil and foundation of tower tube structure shall be subjected to the checking of its seismic bearing capacity as specified in 4.2 of this code, and the following requirements shall be met:

1 As for annular plate and inverted T-shaped foundations, the central angle of the zero stress zone between the foundation base and the soil shall not be greater than 30°.

2 As for independent foundation, the foundation base shall be free from zero stress zone.

12.2.10 As for Class I and II sites at Intensity 7, or Class III site at Intensity 7 with the characteristic value of soil bearing capacity being greater than 160kPa, their water spraying devices may not be subjected to seismic checking, but the relevant requirements for seismic measures shall be met.

12.2.11 The water spraying framework should be subjected to the seismic calculation as a plane frame or bent frame, and shall meet the following requirements:

1 The seismic shear-force of water spraying framework shall be borne by the II-shaped frame under the water tank.

2 The beam or water tank supported by the shaft shall be capable of rotating and horizontally moving with respect to the shaft.

3 If the beam is supported by the corbel of the tube structure wall, it shall be capable of rotating and horizontally moving with respect to that corbel.

12.2.12 The characteristic value of earthquake action effects and other load effects for the water spraying device shall include only the representative values of gravity load effect and the characteristic value of the horizontal and vertical earthquake actions effects, in which the characteristic value of the horizontal earthquake actions effects shall be included in the earthquake hydrodynamic force of the main water tank and the shaft.

12.3 Details for Hyperbolic Cooling Tower

12.3.1 The reinforcement for the tower tube structure wall at both the meridian direction and circumferential direction shall be in double layers, and they shall be determined by calculation but not less than 0.2%; tie bars shall be arranged between rebar in double layers in a staggered way, with the spacing being not greater than 700mm and the diameter being not less than 6mm.

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12.3.2 The meridian and circumferential stressed rebar of tube structure wall shall be staggered at the joints. In the rebar segment with any overlapping length, the ratio of the sectional area of the stressed rebar with joint to the gross sectional area of stressed rebar shall not be greater than 1/3 at the meridian direction and 1/4 at the circumferential direction.

12.3.3 The joints of longitudinal rebar for the foundation, diagonal prop and ring beam of the tower tube structure should be connected mechanically or by welding, and the connecting segment length of joint shall not be less than 35*d* and 500mm; rebar splice shall not be arranged within 500mm to the column bottom. If the rebar diameter is not less than 22mm, the bound and overlapped joints shall not be adopted.

12.3.4 The overlapping length of the bound and overlapped joint of stressed rebar for tower tube structure shall be calculated according to the following formula:

$$L_{LE} = \xi_1 \xi_2 \alpha d f_y / f_t \tag{12.3.4}$$

Where,

L_{LE} -- the overlapping length of bound and overlapped joint of stressed rebar;

ξ_1 -- the correction coefficient for the seismic anchorage length of rebar, which shall be 1.15 at Grades 1 and 2, 1.05 at Grade 3, and 1.0 at Grade 4;

ξ_2 -- the correction coefficient for the overlapping length of stressed rebar, which shall be 1.4 at meridian direction and 1.2 at circumferential direction;

α -- the shape coefficient of rebar, which shall be 0.16 for plain bars and 0.14 for ribbed bars;

d -- the nominal diameter of rebar;

f_y -- the design value of tensile strength of rebar;

f_t -- the design value of axial tensile strength of concrete.

12.3.5 At Intensity 9, the joint of the tube structure body and the stiffening ring of the tower top shall be provided with strengthening measures.

12.3.6 In the plane formed by each pair of diagonal props, the inclination angle of diagonal prop should not be less than 11°, and the slope angles of the ring beam and the diagonal prop axis should be the same.

12.3.7 Both the sectional width and height of the diagonal prop should not be less than 300mm, and both the diameter of the circular column and the incircle diameter of polygonal column should not be less than 350mm; as for rectangular section, the ratio of the diagonal prop calculated length to the short side length of the section shall be 12~20; as for round section, the ratio of its calculated length and its diameter should be 10 ~ 17, and at Intensity 8 and Intensity 9, the smaller value within such range should be adopted. The calculated length of diagonal prop should be the length of such prop multiplied by 0.9 at the radial direction and the length of diagonal prop multiplied by 0.7 at the circumferential direction.

12.3.8 The axial compression ratio of the column should not exceed the limitations specified in Table 12.3.8.

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4 At Intensity 8 and Intensity 9, the upper and lower grillage beams of water spraying device shall be arranged orthogonally at the column, and shall be provided with reliable connection.

12.3.13 If the fill for water spraying is plastic materials and is supported by hangers, and the prop and top beam are single-layer hinged bent, the support for water tank should be portal, and reliable connection shall be provided for such portal and tank.

12.3.14 At Intensity 8 and Intensity 9, the beam and water tank of water spraying framework should not be placed on the corbel of the tube structure wall, unless reliable absorbing and tilting prevention measures are provided.

12.3.15 Beams and water tanks on the tube structure wall and shaft corbel should be provided with the following seismic design measures:

1 The contact area of the beam or water tank bottom and the corbel should be arranged with seismic isolation story.

2 At Intensity 8, buffer layer should be stuck to the beam end or filled into the gap between the beam end and the tube structure wall.

3 At Intensity 9, the corbels of tube structure wall and shaft should be provided with stops at both sides of the beam, and buffer layer should be arranged between the stop and the beam, or, flexible tie device may be arranged between both sides of the beam end and the corbel.

12.3.16 At Intensities 7, 8 and 9, the seismic joints between the inner wall of tower tube structure and the beam, column and water tank of the water spraying device shall not be less than respectively 70mm, 90mm and 120mm.

12.3.17 Settlement joints shall be arranged between the bottom slab of water basin and the foundation of tower tube structure as well as the shaft, and structures crossing the settlement joint, such as the inlet channel and basin partition wall, shall be provided with seismic joints. The larger-diameter intake pipe passing through basin wall should be provided with flexible joint.

12.3.18 The joints of prefabricated main water tank shall be welded firmly, and the seated length of the distributing trough stretching into the main water tank shall not be less than 70mm; at Intensity 8 and Intensity 9, the joints of the main water tank and the distributing trough shall be welded, or be provided with other measures against being pulled off.

12.3.19 At Intensity 8 and Intensity 9, the drift eliminator, fill and fill support grid shall not be floated, and reliable connection shall be provided between them and the beam.

12.3.20 The stirrups within 500mm of the top and the plinth (or above the cup top surface) of the column for water spraying framework, within the full height of the corbel, and within the scope from the corbel top surface to 300mm above the frame beam top surface shall all be densified, and the spacing shall not be greater than 100mm; the minimum diameter of stirrup in densified area shall conform to the requirements specified in Table 12.3.20.

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13 Television Tower

13.1 General Requirement

13.1.1 This chapter is applicable to the seismic design for reinforced concrete and steel Television towers.

13.1.2 The configuration of Television tower and the layout of turrets shall be determined through synthetic analysis according to the building modeling, the process requirements and the rationality of structure stress under earthquake action.

13.1.3 The seismic design for the Television tower higher than 300m and at Intensity 9 shall be researched separately and specially.

13.2 Essentials in Calculation

13.2.1 The seismic calculation of Television tower shall meet the following requirements:

1 As for the Television tower, the seismic influence coefficient shall be determined according to those specified for frequent earthquake in Chapter 5 of this code, and then the earthquake action and the action effect shall be calculated.

2 The seismic precautionary category of Television towers with Class 1 structure safety shall be Category A. As for the Television tower of Category A, in addition to the frequent earthquakes calculation with the time-history analysis method, it shall also be subjected to the elastic-plastic deformation checking under rare earthquake with the same method, and the maximum value of seismic acceleration time-history curve shall be as given in Table 5.1.7 of this code.

3 As for the reinforced concrete Television towers with turrets, which are in Class 2 structure safety and with the heights of 200m and above, and for steel Television towers with turrets, the elastic-plastic deformation check under rare earthquake shall also be performed with the time history analysis method, adopting the maximum value of time-history curve for seismic acceleration given in Table 5.1.7 of this code.

13.2.2 Television towers meeting any of the following requirements may not be subjected to the seismic checking, but they shall conform to the corresponding requirements for seismic measures:

1 The steel Television tower without turrets at Class I, II, or III site of Intensity 7 or at Class I or II site of Intensity 8;

2 The reinforced concrete Television tower without turrets and lower than 200m, at Class I or II site of Intensity 7 and with the fundamental wind pressure not less than $0.4kN/m^2$, or at Class III or IV site of Intensity 7 or Class I or II site of Intensity 8 and with the fundamental wind pressure not less than $0.7kN/m^2$.

13.2.3 The earthquake action calculation of Television tower structure shall meet the following requirements:

1 As for the reinforced concrete Television tower in single-tube structure, the horizontal earthquake actions at the directions of the two principal axes shall be

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------ The End ------