Foreword

This standard is revised from *Code for Seismic Design of Petrochemical Steel Facilities* GB 50761-2012 by Sinopec Engineering Incorporation in cooperation with other involved organizations according to the requirements of Document JIANBIAO [2014] No. 189 issued by the Ministry of Housing and Urban-Rural Development (MOHURD) of the People's Republic of China- "Notice on Printing and Distributing 'the Development and Revision Plan of National Engineering Construction Standards in 2015'".

In revising the standard, the development team incorporated the results of special study in recent years, investigated and summarized the lessons learnt from strong earthquakes occurred both in China and abroad, and discussed, revised, designed on trial and finalized this revision based upon comments from the organizations nationwide involved in survey, design and construction.

This standard consists of 11 chapters and 4 appendixes, covering: general provisions, terms and symbols, basic requirements, seismic action and seismic checking, horizontal vessels, vertical vessels supported by legs, vertical vessels supported by lugs, vertical vessels supported by skirt, spherical tanks supported by legs, vertical cylindrical storage tanks, and tubular heater.

The main contents that are revised include:

1. The slope of the linear descending section of seismic design response spectrum is adjusted.

2. The classification of importance factors in terms of seismic resistance is improved.

3. The adjustment coefficient of seismic action is simplified.

4. The calculation method for horizontal seismic action on the on-framework equipment is supplemented and improved.

5. The damping ratios of vertical cylindrical storage tank and vertical vessel supported by legs are adjusted based on the completed study projects.

6. The relevant clauses and texts are revised according to the comments and suggestions from relevant personnel who have read the draft for comment of the standard.

The Ministry of Housing and Urban-Rural Development of the People's Republic of China is in charge of administration of this standard, China Petrochemical Corporation (Sinopec Group) is responsible for its routine management, and Sinopec Engineering Incorporation (SEI) is in charge of explanation of specific technical contents. Any comments and suggestions made during implementation of this standard are kindly requested to be referred to the Management Team for *Standard for Seismic Design of Petrochemical Steel Equipments* in SEI (Address: Bldg. 21 Anyuan, Anhui Bei Li, Chaoyang District, Beijing, Postcode: 100101) for reference in future revision.

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Contents

1 General provisions

1.0.1 This standard is developed to implement the national laws and regulations on earthquake prevention and disaster reduction, implement the prevention-oriented policy, mitigate the seismic damage through seismic fortification of petrochemical equipments thereby reducing economic loss.

1.0.2 This standard is applicable to the seismic design of the horizontal vessel, vertical vessel supported by legs, vertical vessel supported by lugs, vertical vessel supported by skirt, spherical tank supported by legs, vertical cylindrical storage tank, and tubular heater in petrochemical industry which are used in the area where the design basic acceleration of ground motion is not greater than 0.40*g* or the seismic fortification intensity is 9 degree or less.

1.0.3 For the petrochemical equipment whose seismic design is carried out according to this standard, the equipment body, supports, anchorages shall not be damaged when it is subjected to the precautionary earthquake equivalent to the seismic fortification intensity of the region.

1.0.4 The design parameters of ground motion or the seismic fortification intensity shall be determined in accordance with the relevant provisions of the current national standard GB 18306 *Seismic Ground Motion Parameters Zonation Map of China*. For the construction site where the seismic safety appraisal has been carried out, the seismic fortification shall be in accordance with the approved design parameters of ground motion or the seismic fortification intensity.

1.0.5 In addition to the requirements stipulated in this standard, the seismic design of petrochemical steel equipment shall comply with those stipulated in the current relevant standards of the nation.

2 Terms and symbols

2.1 Terms

2.1.1 Seismic design

A specialized design for the equipment that requires seismic fortification, including seismic calculations and seismic measures.

2.1.2 Seismic fortification intensity

A seismic intensity which is approved according to the authority as specified by the state as the basis for seismic fortification of a region.

2.1.3 Seismic action

The dynamic action on equipment caused by ground motion, including horizontal seismic action and vertical seismic action.

2.1.4 Seismic effect

Internal forces or deformation of equipment produced as a result of seismic action.

2.1.5 Design parameters of ground motion

The time-history curve of acceleration of ground motion, the response spectrum of acceleration, and the peak acceleration which are used for seismic design.

2.1.6 Design basic acceleration of ground motion

A design value of seismic acceleration with a probability of exceedance being 10% over a 50-year design reference period.

2.1.7 Characteristic period of ground motion

In the seismic influence coefficient curve for seismic design, the period value corresponding to the starting point of the descending section which reflects the factors such as seismic magnitude, epicentral distance, and site class.

2.1.8 Seismic influence coefficient

A statistical mean value of the ratio of the maximum acceleration response to the gravitational acceleration of a single-mass point elastic system under seismic action.

2.1.9 Seismic fortification measures

Seismic design contents other than the calculation of seismic action and resistance, including basic requirements for seismic design and details of seismic design.

2.1.10 Details of seismic design

According to the seismic conceptual design principle, various detailed requirements that shall be taken for structural and non-structural parts without the necessity of calculation.

2.1.11 Body

Equipment shell or the framework structure of heater.

2.1.12 Allowable stress design

A design method which uses the principle that the calculated stress of components at the cross-section under the action of design load does not exceed the allowable stress of materials.

2.1.13 Limits state design

An engineering structural design method based on the principle that a structure or member reaches a limit state as required by a predetermined function.

2.2 Symbols

2.2.1 Actions and effects:

F_h—design value of total horizontal seismic action on equipment;

F_v—design value of the total vertical seismic action on the bottom of equipment;

F_{hi}—design value of the horizontal seismic action on mass point i;

F_{hji}—design value of the horizontal seismic action on mass point i under the j^{th} mode;

F_{vi}—design value of the vertical seismic action on equipment mass point i;

F_{hk}—design value of horizontal seismic action on equipment mounted on a structure;

m_{eq}—equivalent total mass of equipment;

m_i、m_j—mass concentrated at mass point i, j, respectively;

m_{eqv}—vertical equivalent mass of equipment;

m_i—mass concentrated at mass point i;

m_j—mass concentrated at mass point j;

S_j—effect produced by horizontal seismic action under the j^{th} mode;

S_h—horizontal seismic effect;

X_{ji}—horizontal relative displacement of mass point i under the j^{th} mode.

2.2.2 Performance and resistance of materials:

E^t—elastic modulus of material at the design temperature;

R_{eL}—yield strength of material;

σ—stress value under the action of load combination;

$[\sigma]$—allowable seismic stress of material;

$[\sigma]^t$—allowable stress of the material at design temperature;

$[\sigma]_t$—allowable tensile stress of material under seismic action;

$[\sigma]_{cr}$—allowable compressive stress of material under seismic action;

τ—value of shear stress under the action of load combination;

$[\tau]$—allowable shear stress of material under seismic action;

$[\tau]_b$—allowable shear stress of materialunder seismic action.

2.2.3 Calculation coefficient:

α_1—horizontal seismic influence coefficient corresponding to the basic natural vibration period of the equipment or structure;

α_j—horizontal seismic influence coefficient corresponding to the natural vibration period of the equipment under the j^{th} mode;

α_{max}—maximum value of the horizontal seismic influence coefficient;

α_{vmax}—maximum value of the vertical seismic influence coefficient;

ϕ—weld joint coefficient;

K_L—adjustment coefficient of allowable seismic stress;

K_m—seismic action amplification factor of equipment mounted on a framework;

ζ—damping ratio of the equipment;

η—seismic importance factor of the equipment;

R_E—adjustment coefficient of seismic action on equipment;

η_1—adjustment coefficient of the slope of the linear descending section;

η_2—damping adjustment coefficient;

γ—attenuation index of the descending section of curve;

γ_j—participation coefficient under the j^{th} mode;

δ—influence index of bending deformation;

λ_m—equivalent mass coefficient;

k—coefficient of calculation.

2.2.4 Other:

h_i, h_j—calculated height of mass point i and j, respectively;

T, T_1—basic natural vibration period of equipment or structure;

T_g—characteristic period;

n—quantity of mass points;

λ—slenderness ratio;

λ_c—critical slenderness ratio;

l_0—calculated length;

$\tilde{i}$—radius of inertia;

δ_e—effective thickness of cross-section.

3 Basic requirements

3.1 Classification of importance factors

3.1.1 In seismic design, the seismic importance factor of equipment shall be classified into the following four(4) categories according to the intended use of the equipment and the hazardness by earthquake damage:

1 Category 1: The equipment except those listed in category 2, category 3 and category 4.

2 Category 2: Category Ⅱ pressure vessels specified in the safety technical specifications for special equipment TSG 21 *Supervision Regulation on Safety Technology for Stationary Pressure Vessel*, category Ⅱ storage tanks as classified according to the current industrial standard AQ 3053 *Safety Technical Code for Vertical Cylindrical Steel Welded Tank*, heaters, and the vertical vessels which have a height of 20m to 80m.

3 Category 3: Category Ⅲ pressure vessels specified in the safety technical specifications for special equipment TSG 21 *Supervision Regulation on Safety Technology for Stationary Pressure Vessel*, category Ⅲ storage tanks as classified according to the current industrial standard AQ 3053 *Safety Technical Code for Vertical Cylindrical Steel Welded Tank*, and the vertical vessels supported by skirts which have a height of more than 80m.

4 Category 4: The equipment for firefighting purposes.

3.1.2 In seismic calculation, the seismic importance factor of the equipment shall be selected according to its seismic importance category as shown in Table 3.1.2.

Table 3.1.2 Importance factor

Category of seismic importance of equipment	Category 1	Category 2	Category 3	Category 4
Importance factor η	0.90	1.00	1.10	1.20

3.2 Seismic influences

3.2.1 Except for heater, the seismic influence on the equipment in region where an earthquake occurs shall be characterized by the design basic acceleration of ground motion and characteristic period of design ground motion spectrum corresponding to the seismic fortification intensity.

3.2.2 The correspondence between the design basic acceleration of ground motion and the seismic fortification intensity is as shown in Table 3.2.2.

Table 3.2.2 Correspondence between the design basic acceleration of ground motion and the seismic fortification intensity

Design basic acceleration of ground motion	0.05g	0.10g	0.15g	0.20g	0.30g	0.40g
Seismic fortification intensity	6	7		8		9

Note: g refers to gravitational acceleration.

3.2.3 The characteristic period of seismic influences shall be determined based on the design earthquake group and site class of the region where the equipment is located. The characteristic period of each design earthquake group is shown in Table 3.2.3.

Table 3.2.3 Characteristic period(s)

Design earthquake group	Site class				
	I_0	I_1	Ⅱ	Ⅲ	Ⅳ
Group 1	0.20	0.25	0.35	0.45	0.65
Group 2	0.25	0.30	0.40	0.55	0.75
Group 3	0.30	0.35	0.45	0.65	0.90

3.2.4 The seismic fortification intensity, design basic acceleration of ground motion and design earthquake group in the main urban centers of China may refer to the relevant provisions of the current national standard GB 50011 *Code for Seismic Design of Buildings*.

3.3 Equipment system design

3.3.1 The equipment system shall meet the following requirements:

1 The equipment should be arranged outdoor on condition of meeting the processing technological requirements.

2 Reasonable transmission path of earthquake action shall be provided.

3 Failure of the entire equipment or loss of seismic resistance due to the failure of equipment parts or auxiliary components shall be avoided.

4 Measures for improving the seismic resistance capability shall be taken for the weak parts of the auxiliary equipment attached to the equipment body.

5 The stiffness and mass of the equipment should be smoothly, and the centroid of its internals and the entire equipment should be located lower.

6 Anchor bolt chairs should be applied to vertical vessel supported by skirt with a height/diameter ratio of greater than 10 or a height of greater than 10m.

7 The external pipeline connected to the equipment shall be able to accommodate the displacement of the connection point between the pipeline and the equipment during the earthquake.

3.3.2 The materials of auxiliary components shall meet the following requirements:

1 The ratio of yield strength to tensile strength of the materials shall not be greater than 0.85.

2 The elongation of the materials of the supporting members shall not be less than 15%.

3 The materials to be welded shall have good weldability and impact toughness in compliance with the design requirements.

4 Under low temperature conditions, the effect of reduced impact toughness of the materials shall be taken into account.

4 Seismic action and seismic checking

4.1 General requirements

4.1.1 The seismic action and seismic checking of equipment shall meet the following requirements:

1 The seismic action on the equipment in horizontal direction shall be calculated and the seismic checking shall be carried out.

2 Where the design basic acceleration of ground motion is 0.20*g* to 0.40g, or the seismic fortification intensity is 8 degree or 9 degree, horizontal vessels with a diameter greater than 4m and the spacing between the two supports greater than 20m, vertical vessel with a height greater than 20m, and stack of heater mounted on ground, the seismic action on the equipment in vertical direction shall be calculated and seismic checking shall be carried out.

3 For the equipment mounted on framework, the seismic amplification effect of the framework shall be taken into account.

4.1.2 Where the design basic acceleration of ground motion is 0.05g, or the seismic fortification intensity is degree 6, the calculating of seismic action for equipments of category 1 and category 2 may not be required, but the requirements for seismic measures shall be met.

4.1.3 The seismic action on the equipment should be calculated according to the following methods:

1 Base shear method may be performed for the following equipments:

1) Vertical vessel with a height of less than or equal to 10m.

2) Vertical vessel with a height/diameter ratio of less than 5, and mass and stiffness relatively uniformly distributed along the height.

3) Vessel which can be treated as an equivalent single mass point system.

2 Mode superposition response spectrum should be performed for the vessels except for those stipulated in Item 1 of this article.

3 Where the design basic acceleration of ground motion is greater than or equal to 0.30*g*, the seismic action on vertical vessels with a height of greater than 120m and a height/diameter ratio of greater than 25 and vertical cylindrical storage tanks with a capacity greater than $15\times10^4m^3$ should be subject to supplemental calculation using time-history analysis method.

4.1.4 When time-history analysis method is performed, the time-history curves consisting of at least two sets of actual strong ground motion records and one set of simulated ground motion shall be selected according to the design earthquake grouping and the site class of the region where the equipment is located. The average seismic influence coefficient curve shall be statistically consistent with the seismic influence coefficient curve used in mode superposition response spectrum method. The maximum value of the acceleration of ground motion for time-history analysis may be shown in Table 4.1.4.

When time-history analysis method is performed, the shear force at base of the equipment calculated with each time-history curve shall not be less than 65% of the calculation result from mode superposition response spectrum method, and the average value of shear forces at base of the equipment calculated with multiple time-history curves shall not be less than 80% of the calculated result from mode superposition response spectrum method.

Table 4.1.4 Maximum values of acceleration of ground motion for time-history analysis(cm/s^2)

Seismic influence	Design basic acceleration of ground motion					
	0.05*g*	0.10*g*	0.15*g*	0.20*g*	0.30*g*	0.40*g*
Frequent earthquake	18	35	55	70	110	140
Precautionary earthquake	50	100	150	200	300	400
Rare earthquake	125	220	310	400	510	620

4.2 Seismic design response spectral of above-ground equipment

4.2.1 The seismic influence coefficient of the equipment shall be determined according to the design basic acceleration of ground motion, site class, design earthquake group, natural vibration period of equipment and damping ratio. The maximum value of the horizontal seismic influence coefficient shall be selected from Table 4.2.1, and the characteristic period shall be selected from Table 3.2.3 according to the site class and design earthquake group.

Table 4.2.1 Maximum value of horizontal seismic influence coefficient

Seismic influence	Design basic acceleration of ground motion					
	0.05*g*	0.10*g*	0.15*g*	0.20*g*	0.30*g*	0.40*g*
Frequent earthquake	0.04	0.08	0.12	0.16	0.24	0.32
Precautionary earthquake	0.12	0.23	0.34	0.45	0.68	0.90
Rare earthquake	0.28	0.50	0.72	0.90	1.20	1.40

4.2.2 The damping adjustment coefficient and shape parameters of the seismic influence coefficient curve of the equipment(Figure 4.2.2)shall meet the following requirements:

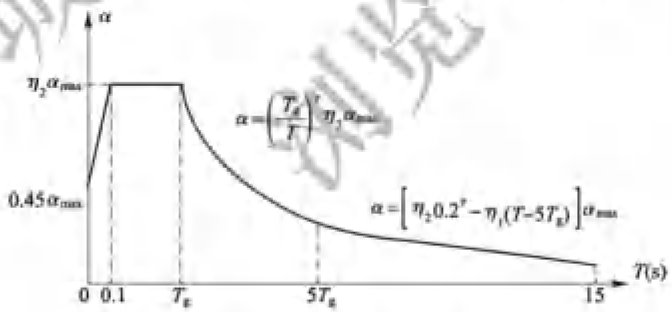


Figure 4.2.2 Seismic influence coefficient curve

α—horizontal seismic influence coefficient; α_{max}—maximum value of horizontal seismic influence coefficient; η_1—adjustment coefficient of descending slope of linear descending section; γ—attenuation index of curve descending section; T_g—characteristic period; η_2—damping adjustment coefficient; T—natural vibration period of equipment

1 The seismic influence coefficient curve is divided into the following parts:

1)Linear ascending section, where the natural vibration period of the equipment is lessthan 0.1s.

2)Horizontal section, where the natural vibration period range from 0.1s to characteristic period.

3)Curve descending section, where the natural vibration period range from characteristic period to 5 times the characteristic period.

4)Linear descending section, where the natural vibration period range from 5 times the characteristic period to 15s.

2 The attenuation index of the curve descending section shall be determined according to the following formula:

$$\gamma = 0.9 + \frac{0.05 - \zeta}{0.3 + 6\zeta} \qquad (4.2.2\text{-}1)$$

Where, γ—attenuation index of the curve descending section;

ζ—damping ratio of equipment.

3 The adjustment coefficient of descending slope of linear descending section shall be determined according to the following formula:

$$\eta_1 = \frac{\eta_2 0.2^{\gamma} - 0.03}{14} \qquad (4.2.2\text{-}2)$$

Where, η_1—adjustment coefficient of descending slope of linear descending section, which is taken as 0 if it is lessthan 0.

4 The damping adjustment coefficient shall be determined according to the following formula:

$$\eta_2 = 1 + \frac{0.05 - \zeta}{0.08 + 1.6\zeta} \qquad (4.2.2\text{-}3)$$

Where, η_2—damping adjustment coefficient, which is taken as 0.55 if it is less than 0.55.

5 If the calculated value of horizontal seismic influence coefficient is less than 0.05 $\eta_2 \alpha_{max}$, it is taken as 0.05 $\eta_2 \alpha_{max}$.

4.3 Horizontal seismic action of above-ground equipment

4.3.1 When base shear method is performed, the design value of total horizontal seismic action on equipment (Figure 4.3.1) shall be calculated according to the following formulas:

$$F_h = \eta R_E \alpha_1 m_{eq} g \qquad (4.3.1\text{-}1)$$

$$m_{eq} = \lambda_m \sum_{i=1}^{n} m_i \qquad (4.3.1\text{-}2)$$

$$F_{hi} = \frac{m_i h_i^2}{\sum_{j=1}^{n} m_j h_j^2} F_h \qquad (4.3.1\text{-}3)$$

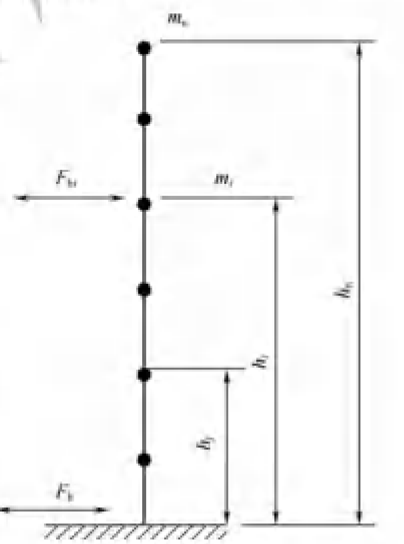


Figure 4.3.1 Diagram of calculation for total horizontal seismic action on equipment

Where, F_h—design value of total horizontal seismic action on equipment (N);

η—seismic importance factor of the equipment, which is selected from Table 3.1.2;

R_E—adjustment coefficient of seismic action on equipment, which is selected from Table 4.3.1-1;

α_1—horizontal seismic influence coefficient corresponding to the basic natural vibration period of the equipment, which is selected according to the requirements of Section 4.2 in this standard;

m_{eq}—equivalent total mass of equipment (kg);

λ_m—equivalent mass coefficient, which is taken as 1 for single mass point system and 0.85 for multiple mass point system;

m_i, m_j—mass concentrated at mass point i or j (kg);

F_{hi}—design value of horizontal seismic action at mass point i (N);

h_i, h_j—calculated height of mass point i or j (mm);

δ—influence index of bending deformation, which is selected from Table 4.3.1-2;

n—quantity of mass points.

Table 4.3.1-1 Adjustment coefficient of horizontal seismic action

Equipment type	R_E
Horizontal vessel	0.45
Vertical vessel supported by legs	0.45
Vertical vessel supported by lugs	0.45
Vertical vessel supported by skirt	0.45
Spherical tank	0.45
Vertical cylindrical storage tank	0.40

Table 4.3.1-2 Influence index of bending deformation

Basic natural vibration period of equipment T_1(s)	<0.5	0.5~2.5	>2.5
δ	1.0	$0.75+0.5T_1$	2

4.3.2 When the mode superposition response spectrum method is performed, the design value of the seismic action and seismic effect on the vessels shall meet the following requirements:

1 The design value of horizontal seismic action at the mass point i under the j^{th} mode shall be determined according to the following formulas:

$$F_{hji} = \eta R_E \alpha_j \gamma_j X_{ji} m_i g \tag{4.3.2-1}$$

$$\gamma_j = \frac{\sum_{i=1}^{n} X_{ji} m_i}{\sum_{i=1}^{n} X_{ji}^2 m_i} \tag{4.3.2-2}$$

Where, F_{hji}—design value of horizontal seismic action at mass point i under the j^{th} mode (N);

α_j—horizontal seismic influence coefficient corresponding to natural vibration period of the equipment under the j^{th} mode, which is determined according to the requirements in 4.2;

γ_j—participation coefficient under the j^{th} mode;

X_{ji}—horizontal relative displacement of mass point i under the j^{th} mode.

2 The horizontal seismic effect shall be determined according to the following formula:

$$S_h = \sqrt{\sum S_j^2} \tag{4.3.2-3}$$

Where, S_h—horizontal seismic effect;

S_j—effect produced by horizontal seismic action under the j^{th} mode, the first two or three orders of vibration mode are taken. If the basic natural vibration period is greater than 1.5s, the number of vibration mode shall not be less than 3.

4.4 Horizontal seismic action of on-framework equipment

4.4.1 Where the mass ratio of the framework to the equipment is greater than or equal to 2, the horizontal seismic action on the equipment should be calculated according to the requirements in this section.

4.4.2 The design value of horizontal seismic action on the equipment mounted on the framework may be calculated according to the following formula:

$$F_{hk} = K_m \eta R_E \alpha_1 m_{eq} g \qquad (4.4.2)$$

Where, F_{hk}—design value of horizontal seismic action on the equipment mounted on the framework(N);

K_m—amplification factor of seismic action on the equipment mounted on the framework, which is selected from Table 4.4.2.

Table 4.4.2 Amplification factor of seismic action on the equipment mounted on the framework

Floor of framework	First floor	Second floor	Third floor	Fourth floor	Fifth floor and above
Amplification factor	1.2	1.4	1.6	1.8	2.0

Note: The height of each framework floor may be taken as 4m to 5m.

4.4.3 If the structural parameters of the framework are known, the design value of the horizontal seismic action on the equipment mounted on the framework may be calculated according to the requirements of Appendix A in this standard.

4.5 Vertical seismic action

4.5.1 The design value of vertical seismic action on a vertical equipement (Figure 4.5.1) shall be calculated according to the following requirements:

1 The design value of total vertical seismic action on the base of equipment shall be calculated according to the following formula:

$$F_v = \eta R_E \alpha_{vmax} m_{eqv} g \qquad (4.5.1\text{-}1)$$

Where, F_v—design value of total vertical seismic action on the base of equipment(N);

α_{vmax}—maximum value of vertical seismic influence coefficient, which is taken as 65% of the maximum value of horizontal seismic influence coefficient;

m_{eqv}—vertical equivalent mass of equipment(kg), which is taken as 75% of total mass of the equipment.

2 The vertical seismic action on any mass point i of the equipment may be calculated according to the following formula:

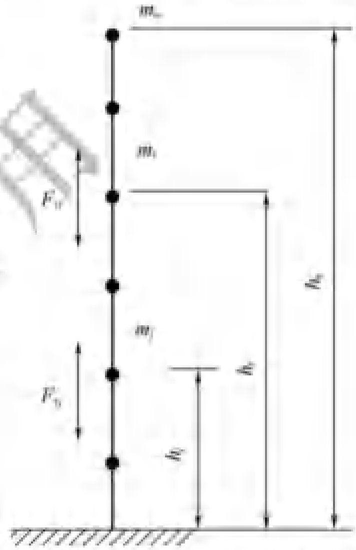


Figure 4.5.1 Diagram of vertical seismic action on equipment

$$F_{vi} = \frac{m_i h_i}{\sum_{i=1}^{n} m_i h_i} F_v \qquad (4.5.1\text{-}2)$$

Where, F_{vi}—design value of vertical seismic action on mass point i of the equipment(N).

4.5.2 The design value of vertical seismic action on horizontal equipment may be taken as 10%, 15% and 20% of the total gravity load of the equipment when the design basic acceleration of ground motion is 0.20g, 0.30g and 0.40g, respectively.

4.6 Combinations of loads

4.6.1 If limits state design is performed, the combination of seismic action and other loads shall be in accordance with the relevant requirements of the current national standard GB 50011 *Code for Seismic Design of Buildings*.

4.6.2 If allowable stress design is performed, the combination of seismic action and other loads shall be in accordance with the following principles:

1 The gravity load of the equipment, including the self-weight of the equipment (including internals and packings, etc.), the gravity load of the contents under normal operating conditions, and the gravity load of the auxiliary equipment and thermal insulation materials, lining, piping, stairs, and platforms, etc.

2 Pressure, including internal pressure, external pressure or maximum differential pressure.

3 Static head of liquid.

4 Horizontal wind load, the combination coefficient of horizontal wind load is taken as 0.25 for vertical equipment and spherical tank, and zero(0) for other equipment.

5 Design value of horizontal and vertical seismic action.

6 Combination coefficient of snow load is taken as 0.5; at high-temperature parts and where the load bearing surface is small, taken as zero(0).

7 Other loads, including the reaction forces by the saddle, skirt, legs, lugs and other types of supporting parts, the forces caused by the connected piping and other components, the forces caused by temperature gradient or differential thermal expansion, etc.

8 Live loads, including personnel, tools, maintenance, impact, vibration and other main movable loads.

4.7 Seismic checking

4.7.1 If limits state design is performed, the seismic checking shall be carried out in accordance with the relevant requirements of the current national standard GB 50011 *Code for Seismic Design of Buildings*.

4.7.2 If allowable stress design is performed, the seismic checking shall be carried out according to the following requirements:

1 In seismic checking of the equipment, the stress at the checked parts under the action of load combination shall meet the requirements of the following formulas:

$$\sigma \leqslant \phi[\sigma] \quad (4.7.2\text{-}1)$$

$$\tau \leqslant [\tau] \quad (4.7.2\text{-}2)$$

Where, σ—stress under the action of load combination (MPa);

ϕ—weld joint coefficient, which is taken as 1.0 under compression;

$[\sigma]$—allowable seismic stress of the material (MPa);

τ—shear stress under action of load combination (MPa);

$[\tau]$—allowable seismic shear stress of the material (MPa).

2 The allowable stress for seismic checking of equipment shall be determined according to the following requirements:

1) For equipment body and supporting members, it may be calculated according to the following formula:

$$[\sigma] = K_1[\sigma]^t \quad (4.7.2\text{-}3)$$

Where, $[\sigma]$—allowable seismic stress of material (MPa);

K_1—adjustment coefficient of allowable seismic stress, which is taken as 1.2 for equipment body and 1.33 for supporting members;

$[\sigma]^t$—allowable stress of material at design temperature(MPa).

2)For anchor bolts, it may be calculated according to the following formula:

carbon steel $$[\sigma]_b = 0.75R_{eL} \qquad (4.7.2\text{-}4)$$

low alloy steel $$[\sigma]_b = 0.6R_{eL} \qquad (4.7.2\text{-}5)$$

carbon steel and low alloy steel $$[\tau]_b = 0.8[\sigma]_b \qquad (4.7.2\text{-}6)$$

Where, $[\sigma]_b$—allowable seismic tensile stress of material(MPa);

R_{eL}—yield strength of material(MPa);

$[\tau]_b$—allowable seismic shear stress of material(MPa).

3)For anchor attachments, it may be according to the following formula applies:

$$[\sigma]_b = K_L[\sigma]^t \qquad (4.7.2\text{-}7)$$

Where, K_L—adjustment coefficient of allowable seismic stress, which may be taken as 1.33;

$[\sigma]^t$—allowable stress of material at design temperature(MPa).

4)The allowable compressive stress of anchor attachment and supporting member may be calculated according to the following requirements:

If $\lambda \leqslant \lambda_c$:

$$[\sigma]_{bc} = \frac{1 - 0.4\left(\frac{\lambda}{\lambda_c}\right)^2}{\frac{3}{2} + \frac{2}{3}\left(\frac{\lambda}{\lambda_c}\right)^2}[\sigma]^t \qquad (4.7.2\text{-}8)$$

If $\lambda > \lambda_c$:

$$[\sigma]_{bc} = \frac{0.277}{\left(\frac{\lambda}{\lambda_c}\right)^2}[\sigma]^t \qquad (4.7.2\text{-}9)$$

$$\lambda = \frac{kl_k}{i} \qquad (4.7.2\text{-}10)$$

$$\lambda_c = \sqrt{\frac{\pi^2 E^t}{0.6[\sigma]^t}} \qquad (4.7.2\text{-}11)$$

Where, λ—slenderness ratio;

λ_c—critical slenderness ratio;

$[\sigma]_{bc}$—allowable seismic compressive stress of material(MPa);

k—calculation coefficient, which is selected from Table 4.7.2;

l_k—calculation length(mm);

i—radius of inertia(mm), which is taken as $0.289\delta_e$ for rectangular cross-section, where δ_e is effective thickness of cross-section;

E^t—elastic modulus of material at design temperature(MPa).

Table 4.7.2 Calculation coefficient *k*

Boundary condition	Simply supported at both ends	Fixed at one end and free at the other end	Fixed at both ends	Fixed at one end and simply supported at the other end
k	1	2	0.5	0.7

5)The allowable stress of weld joint between the supporting member and the equipment body may be calculated according to the following formulas:

$$[\sigma] = K_L[\sigma]^t \qquad (4.7.2\text{-}12)$$

$$[\tau] = 0.8[\sigma] \tag{4.7.2-13}$$

Where, K_1—adjustment coefficient of allowable seismic stress, which is taken as 1.2;

$[\sigma]$—allowable stress of material at design temperature (MPa), which is taken as the smaller of allowable stress of accessories and that of equipment body material.

5 Horizontal vessels

5.1 General requirements

5.1.1 The seismic design of horizontal vessels shall comply with the requirement of this chapter.

5.1.2 The basic vibration natural period of horizontal vessel may be taken as 0.10s; if more than one vessels are stacked together, the basic natural period may be taken as 0.15s.

5.2 Seismic action and seismic checking

5.2.1 In calculation of horizontal seismic action on horizontal vessel, the seismic influence coefficient may be taken as the maximum value according to the requirement of Article 4.2.1 in this standard in respect of precautionary earthquake.

5.2.2 For horizontal vessel mounted on ground, their axial and lateral horizontal seismic action shall be calculated according to the requirements of Section 4.3 in this standard; for horizontal vessel mounted on frameworks, their axial and lateral horizontal seismic action may be calculated respectively in accordance with the requirements of Section 4.4 in this standard.

5.2.3 The damping ratio of horizontal vessel may be taken as 0.05.

5.2.4 The stacked horizontal vessels may be regarded as a multiple-degree-of-freedom system in both axial and lateral direction(Figure 5.2.4). The seismic action on stacked horizontal vessels mounted on ground may be calculated according to Section 4.3 and the seismic influence coefficient may be taken as the maximum value of horizontal seismic influence coefficient. The total seismic action on stacked horizontal vessels mounted on framework and horizontal seismic action on individual mass points may be calculated according to Section 4.4 in this standard.

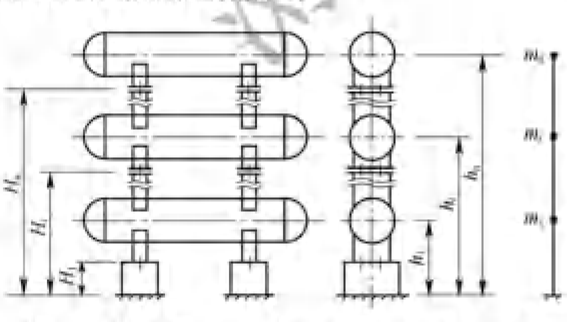


Figure 5.2.4 Diagram of stacked horizontal vessels

H_1, H_i, H_n—height of base plate of support of vessels above ground or framework floor;

h_1, h_i, h_n—height of centroid of vessel above ground or framework floor;

m_1, m_i, m_n—mass of vessel concentrated at mass point 1, i and n respectively

5.2.5 The body, supports, anchor bolts, etc. of horizontal vessel shall be subjected to seismic checking and shall comply with the requirements of Section 4.7 in this standard.

5.3 Details of seismic design

5.3.1 The quantity of anchor bolts for each support of vessel shall not be less than 2, the bolt diameter should not be less than M16, and the nuts shall be anti-loosening.

5.3.2 The anchor bolts on sliding support shall be provided with features for limiting the lateral displacement of vessel.

5.3.3 Where the seismic fortification intensity is greater than or equal to 7 degree, the support shall be welded to the vessel body.

6 Vertical vessels supported by legs

6.1 General requirements

6.1.1 The seismic design of vertical vessel with a height H of not greater than 10m (including the height of leg) and a height/diameter ratio of not greater than 5 (Figure 6.1.1) shall comply with the requirements of this chapter.

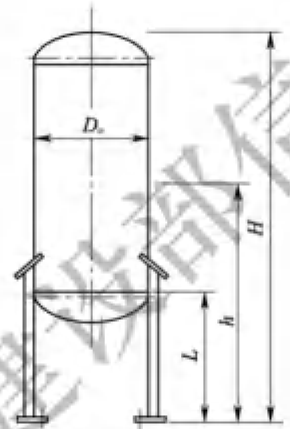


Figure 6.1.1 Diagram of vertical vessel supported by legs

6.1.2 For vertical vessel supported by legs mounted on ground with diameter less than 1.2m, height less than 3m (including the height of legs), and leg height less than 0.5m, if the seismic fortification intensity is 6 degree or 7 degree, seismic checking of the vessel may not be required, but the requirements on details of seismic design shall be met.

6.2 Natural vibration period

6.2.1 The basic natural vibration period of vertical vessel supported by legs may be calculated according to the following formula:

$$T_1 = 2\pi\sqrt{\frac{m_e}{1000K}} \tag{6.2.1}$$

Where, T_1—basic natural vibration period of vessel(s);

m_e—mass of vessel(kg);

K—lateral stiffness of the supporting structure (N/mm), which is calculated from the following formulas of Article 6.2.2 in this standard.

6.2.2 The lateral stiffness of supporting structure of vertical vessel supported by legs shall be calculated according to the following formulas:

$$K = \frac{1}{\frac{\lambda_c}{K_1} + \frac{1}{K_2}} \tag{6.2.2-1}$$

$$K_1 = \frac{3nEA_Z D_b^2}{2L^3} \tag{6.2.2-2}$$

$$K_2 = \frac{nK_c}{1 + \frac{LK_c}{GA_Z}} \tag{6.2.2-3}$$

$$K_v = \frac{4E(I_1 + I_2)}{L^3} \tag{6.2.2-4}$$

$$\lambda_r = \left(\frac{h}{L}\right)^2 - \frac{h}{L} + 4 \tag{6.2.2-5}$$

Where, K—lateral stiffness of supporting structure(N/mm);

K_1—bending stiffness of supporting structure(N/mm);

K_2—shear stiffness of supporting structure(N/mm);

K_v—bending stiffness of single leg(N/mm);

λ_r—correction coefficient of height ofcentroid of vessel;

n—quantity of legs;

E—elastic modulus of leg material(MPa);

A_Z—cross-sectional area of single leg(mm^2);

D_b—diameter of center circle of legs(mm);

L—height of leg(mm);

G—elastic shear modulus of leg material(MPa);

I_1—tangential moment of inertia of cross-section of single leg(mm^4);

I_2—moment of inertia of radial horizontal cross-section of single leg(mm^4);

h—distance from top surface of foundation to the centroid of vessel(mm).

6.3 Seismic action and seismic checking

6.3.1 In calculation of horizontal seismic action of vertical vessel supported by legs, the seismic influence coefficient shall comply with the requirement of Section 4.2 in this standard in respect of precautionary earthquake.

6.3.2 The seismic action on vertical vessel supported by legs mounted on ground shall be calculated in accordance with Article 4.3.1 in this standard. The seismic action on vertical vessel supported by legs mounted on frameworks shall be calculated in accordance with Section 4.4 in this standard.

6.3.3 The damping ratio of vertical vessel supported by legs may be taken as 0.05.

6.3.4 For vertical vessel supported by legs, the seismic checking of shell cylinder, legs and weld joints between the shell and legs as well as of anchor bolts shall meet the requirements of Section 4.7 in this standard.

6.3.5 The method of seismic checking of vertical vessels supported by legs may comply with the requirements of Appendix B in this standard.

6.4 Details of seismic design

6.4.1 The quantity of legs shall not be less than 3, where the seismic fortification intensity is 8 or 9 degree, and the diameter of vessel is greater than 800mm, the quantity of legs should not be less than 4.

6.4.2 Each leg shall be provided with anchor bolt whose diameter of bolt should not be less than M16. Nuts shall be anti-loosening .

7 Vertical vessels supported by lugs

7.1 General requirements

7.1.1 The seismic design of vertical vessel supported by lugs(Figure 7.1.1)shall meet the requirements of this chapter.

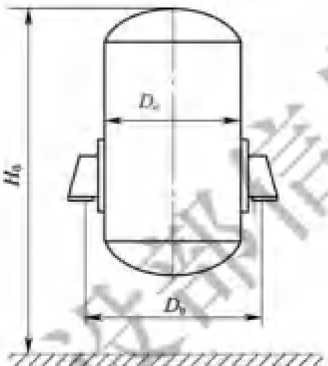


Figure 7.1.1 Diagram of vertical vessel supported by lugs

7.1.2 For vertical vessel supported by lugs with diameter less than 2m and distance between tangent lines less than 5m, where the seismic fortification intensity is 6 or 7 degree, seismic checking of the vessel may not be required, but the requirements on details of seismic design shall be met.

7.2 Natural vibration period

7.2.1 The basic natural vibration period of vertical vessel supported by lugs may be calculated according to the following formula:

$$T_1 = 0.56 + 0.4 \times 10^{-3} \frac{H_0^2}{D_0} \quad (7.2.1)$$

Where, T_1—basic natural vibration period of vertical vessel supported by lugs(s);

H_0—height of vessel top above ground(mm);

D_0—outside diameter of vessel(mm).

7.2.2 Where the length between tangent lines is less than 3m, T_1 may be taken as 0.3s.

7.3 Seismic action and seismic checking

7.3.1 In calculation of horizontal seismic action of vertical vessel supported by lugs, the seismic influence coefficient shall comply with the requirements of Section 4.2 in this standard in respect of precautionary earthquake

7.3.2 The horizontal seismic action on vertical vessel supported by lugs shall be calculated in accordance with Article 4.3.1.

7.3.3 The damping ratio of vertical vessel supported by lugs may be taken as 0.03.

7.3.4 For vertical vessel supported by lugs, the seismic checking of shell cylinder, lug and weld joints between the shell and lugs as well as of anchor bolts shall meet the requirements of Section 4.7 in this standard.

7.3.5 The method of seismic checking of vertical vessel supported by lugs may comply with the requirements of Appendix C in this standard.

7.4 Details of seismic design

7.4.1 The lugs should be located above the centroid of vessel.

7.4.2 The quantity of lugs should not be less than 4 and shall be even. Where the diameter of vessels is less than 1000mm, the quantity of lugs shall not be less than 2.

7.4.3 Each lug shall be provided with anchor bolt, nuts shall be anti-loosening.

8 Vertical vessels supported by skirt

8.1 General requirements

8.1.1 The seismic design of vertical vessel supported by skirt shall meet the requirements of this chapter.

8.1.2 For the vessel with a height greater than 20m high and located where the design basic acceleration of ground motion is greater than or equal to 0.20g or the seismic fortification intensity is 8 or 9 degree, the effect of vertical seismic action shall be taken into account.

8.2 Natural vibration period

8.2.1 The natural vibration period calculation of vertical vessel supported by skirt may be simplified into a multiple-mass point system.

8.2.2 The basic natural vibration period of vertical vessel supported by skirt which have a uniform diameter and thickness mounted on ground may be calculated according to the following formula:

$$T_1 = 90.33H\sqrt{\frac{m_0 H}{E^t D_i^3 \delta_e}} \times 10^{-3} \tag{8.2.2}$$

Where, T_1—basic natural vibration period of vessel(s);

H—distance from top surface of foundation to top of vessel(mm);

m_0—total mass of vessel(kg);

E^t—elastic modulus of material(MPa);

D_i—inside diameter of vessel cylinder(mm);

δ_e—effective thickness of vessel cylinder(mm).

8.2.3 For a vertical vessel mounted on ground with non-uniform diameter or thickness, the vessel whose diameter, thickness and material change as along height may be treated as a multiple-mass point system (Figure 8.2.3). Its basic natural vibration period may be calculated according to the following formulas:

$$T_1 = 114.8\sqrt{\sum_{i=1}^{n} m_i \left(\frac{h_i}{H}\right)^3 \left(\sum_{i=1}^{n} \frac{H_i^3}{E_i^t I_i} - \sum_{i=2}^{n} \frac{H_i^3}{E_{i-1}^t I_{i-1}}\right)} \times 10^{-3} \tag{8.2.3-1}$$

Cylindrical section:

$$I_i = \frac{\pi}{8}(D_i + \delta_{ei})^3 \delta_{ei} \tag{8.2.3-2}$$

Conic section:

$$I_i = \frac{\pi D_{ie}^2 D_{if}^2 \delta_{ei}}{4(D_{ie} + D_{if})} \tag{8.2.3-3}$$

Where, T_1—basic natural vibration period of vessel(s);

m_i—mass of the i^{th} calculated section of vessel(kg);

h_i—distance from the i^{th} section centroid of vessel to top surface of foundation(mm);

H—total distance from the top surface of foundation to top surface of vessel(mm);

H_i—distance from top surface of vessel to bottom cross-section of the i^{th} section(mm);

E_i^t、E_{i-1}^t—elastic modulus of the i^{th} and $(i-1)^{th}$ section of shell(MPa);

I_i, I_{i-1}—moment of inertia of cross-section of the i^{th} and $(i-1)^{th}$ section of shell(mm^4);

D_i—inside diameter of the i^{th} section of cylinder(mm);

δ_e—effective thickness of cylindrical or conic shell at a calculated cross-section(mm);

D_a—inside diameter at large-end of conic shell(mm);

D_b—inside diameter at small-end of conic shell(mm).

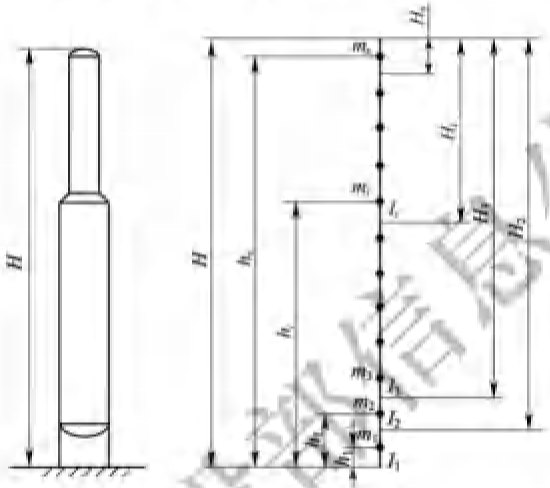


Figure 8.2.3 Diagram of multiple-mass point system of vertical vessel supported by skirt

8.2.4 The natural vibration period of vertical vessel supported by skirt as mounted on framework may be calculated according to the following requirements:

1 The framework shall be regarded as an integral part of the vessel, each floor of framework may be simplified into one mass point, and the floors stiffness of the framework may be converted based on displacement equivalent principle. The natural vibration period of the vessel may be calculated using mode-superposition method.

2 For vertical vessel supported by skirt with a height/diameter ratio of less than or equal to 5 and a wall thickness of less than or equal to 30mm, the basic natural vibration period may be calculated using Formula(7.2.1).

8.3 Seismic action and seismic checking

8.3.1 The horizontal seismic influence coefficient of vertical vessel supported by skirt shall comply with the requirements of Section 4.2 in this standard. The maximum value of horizontal seismic influence coefficient shall be taken according to Table 4.2.1 for precautionary earthquake.

8.3.2 The horizontal seismic action on vertical vessel supported by skirt shall be calculated according to the requirements of Section 4.3 in this standard.

8.3.3 For vertical vessel supported by skirt with a height less than or equal to 10m or a height/diameter ratio of less than or equal to 5, the horizontal seismic action on them may be calculated using base shear method, and the seismic influence coefficient may be taken as the maximum value of horizontal seismic influence coefficient for the precautionary earthquake.

8.3.4 For vertical vessel supported by skirt with a height greater than 10m or a height/diameter ratio of greater than 5, the horizontal seismic action on them may be calculated using mode-superposition method.

8.3.5 The damping ratio of vertical vessel supported by skirt may be taken according to the following requirements:

1 Where the basic natural vibration period of the vessel is less than or equal to 1.5s, the damping ratio may be taken as 0.035.

2 Where the basic natural vibration period of the vessel is greater than 1.5s but less than or equal to 2.0s, the damping ratio may be calculated according to the following formula:

$$\zeta = 0.11 - 0.05T_1 \tag{8.3.5}$$

3 Where the basic natural vibration period of the vessel is greater than 2.0s, the damping ratio may be taken as 0.01.

8.3.6 The vertical seismic action on vertical vessel supported by skirt shall be calculated according to the requirements of Section 4.5 in this standard.

8.3.7 For vertical vessel supported by skirt, the shell, skirt cylinder, base ring, anchor bolt chairs, weld joint between skirt and shell, weld joint between anchor bolt chair and skirt cylinder and anchor bolts shall be subjected to seismic checking and shall meet the requirements of Section 4.7 in this standard.

8.4 Details of seismic design

8.4.1 The platform of a vessel should not be directly connected to other vessel or structure.

8.4.2 The external heavy auxiliary equipment of a vessel should be provided with a separate supporting structure, and should not be directly supported by the vessel.

8.4.3 The internal load-bearing members of a vessel shall be securely connected to the shell.

8.4.4 Where the height/diameter ratio of the vessel is greater than 5 and the seismic fortification intensity is greater than 7 degree, the vessel cylinder should not be connected to the skirt with lapping joint.

8.4.5 Where the diameter of a vessel is greater than or equal to 800mm, the diameter of anchor bolts shall not be less than M24, the quantity of anchor bolts should not be less than 8, and the nuts shall be anti-loosening.

9 Spherical tanks supported by legs

9.1 General requirements

9.1.1 The seismic design of a spherical tank with adjustable or fixed type tie rods which is supported by columns along the equator(with the centerlines of the columns being tangent to or secant to the inner wall of the spherical shell)shall meet the requirements of this chapter.

9.1.2 In calculation of seismic action on spherical tanks, the effect of contents shall be taken into account.

9.2 Natural vibration period

9.2.1 The equivalent mass of spherical tank under operating condition shall be calculated according to the following formulas:

$$m_{eq} = m_1 + m_2 + m_3 + 0.5m_6 + m_7 \quad (9.2.1\text{-}1)$$

$$m_2 = m_L \varphi \quad (9.2.1\text{-}2)$$

Where, m_{eq}—equivalent mass of spherical tank under operating condition(kg);

m_1—mass of spherical shell(kg);

m_2—effective mass of stored liquid(kg);

m_3—mass of insulation materialr of spherical tank(kg);

m_6—mass of columns and tie rods(kg);

m_7—mass of accessories (kg) , including manholes, nozzles, level gauges, internals, spraying devices, safety valve, ladders and platforms etc;

m_L—mass of stored liquid in spherical tank(kg);

φ—effective mass coefficient of stored liquid, which is obtained from Figure 9.2.1 according to the liquid fullness in spherical tank.

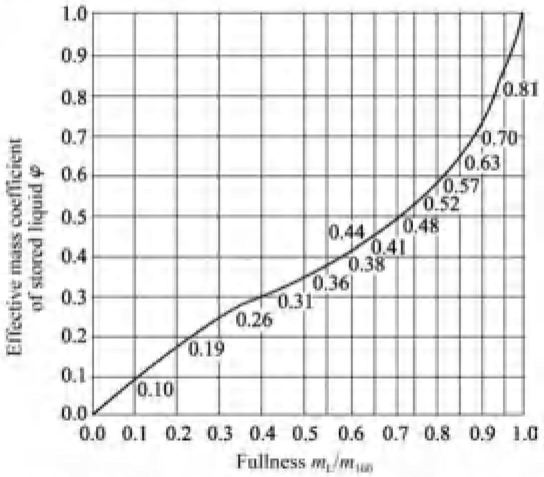


Figure 9.2.1 Diagram of effective mass coefficient of stored liquid

m_{100}—mass of full liquid in spherical tank

9.2.2 The horizontal stiffness of support system of spherical tank (Figure 9.2.2) shall be calculated according to the following formulas:

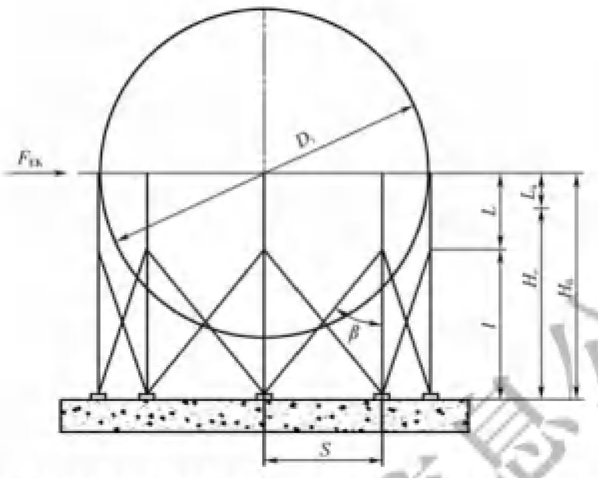


Figure 9.2.2 Diagram of support system of spherical tank

$$K=\frac{1}{\frac{1}{K_1}+\frac{1}{K_2}} \quad (9.2.2\text{-}1)$$

$$K_1=\frac{3nE_sAD_b^2}{8H_0^3} \quad (9.2.2\text{-}2)$$

$$K_2=nK_c\left[\frac{2C_1}{C_2+\frac{4SK_c}{E_sA'}}+1\right] \quad (9.2.2\text{-}3)$$

$$K_c=\frac{3E_sI}{H_c^3} \quad (9.2.2\text{-}4)$$

$$A'=\frac{1}{\frac{C_3}{A_T\sin^2\beta}+\frac{C_4\cot^3\beta}{A}} \quad (9.2.2\text{-}5)$$

$$C_1=0.25\lambda_c^2(3-\lambda_c)^2 \quad (9.2.2\text{-}6)$$

$$C_2=\lambda_c^2(1-\lambda_c)^2(3+\lambda_c) \quad (9.2.2\text{-}7)$$

$$\lambda_c=\frac{l}{H_c} \quad (9.2.2\text{-}8)$$

$$H_c=H_0-L_a \quad (9.2.2\text{-}9)$$

$$L_a=\frac{1}{2}\sqrt{\frac{d_oD_i}{2}} \quad (9.2.2\text{-}10)$$

$$\beta=\tan^{-1}\frac{S}{l} \quad (9.2.2\text{-}11)$$

Where, K—lateral stiffness of support system of spherical tank(N/mm);

K_1—bending stiffness of support system of spherical tank(N/mm);

K_2—shear stiffness of support system of spherical tank(N/mm);

n—quantity of columns;

E_s—elastic modulus of column material under room temperature(MPa);

A—cross-sectional area of single column(mm^2);

D_b—diameter of columns center circle(mm);

H_0—distance from bottom surface of base plate of column to equator of spherical shell (mm);

S—distance between adjacent columns(mm);

I—moment of inertia of cross-section of single column(mm^4);

H_c—effective height of column(mm);

A_T—effective cross-sectional area of single tie rod(mm^2);

β—included angle between tie rod and column(°);

l—distance from bottom surface of base plate of column to center of upper pin(mm);

L_w—0.5 times length of weld joint between column and spherical shell(mm);

d_c—outside diameter of column(mm);

D_i—inside diameter of spherical shell(mm);

K_c, A', C_1, C_T, λ_t—calculated parameter or coefficient;

C_3,C_4—structural type coefficient of tie rod, which is consulted from Table 9.2.2 based on structural form of tie rod.

Table 9.2.2 Structural type coefficient of tie rod

Coefficient	Adjustable type	Fixed type
C_3	1.0	0.5
C_4	1.0	0

9.2.3 The basic natural vibration period of spherical tank shall be calculated according to the following formula:

$$T_1 = 2\pi\sqrt{\frac{m_{eq}}{1000K}} \tag{9.2.3}$$

Where, T_1—basic natural vibration period of spherical tank(s).

9.3 Seismic action and seismic checking

9.3.1 In calculation of horizontal seismic action on spherical tank, the seismic influence coefficient shall be determined according to Section 4.2 in this standard in respect of precautionary earthquake.

9.3.2 The horizontal seismic action on spherical tank shall be calculated in accordance with Article 4.3.1 in this standard.

9.3.3 The damping ratio of spherical tank may be taken as 0.035.

9.3.4 The total bending moment caused by horizontal seismic action on the upper section of column shall be calculated according to the following formula:

$$M = F_{EK}L \tag{9.3.4}$$

Where, M—total bending moment caused by horizontal seismic action on the upper section of column (N·mm);

F_{EK}—design value of horizontal seismic action on spherical tank(N);

L—distance from equatorial plane of spherical shell to center of upper pin(mm).

9.3.5 The seismic checking of columns, weld joints between columns and spherical shell, tie rods and accessories, base plate of columns and anchor bolts shall comply with the requirements of Section 4.7 in this standard.

9.4 Details of seismic design

9.4.1 The diameter of anchor bolts shall not be less than M24, and nuts shall be anti-loosening.

9.4.2 The weld joints between the spherical shell and columns, column and lugs, tie rods and wing plates, column and base plate shall be equal strength joints as that of the corresponding thinner parts. The weld joints shall be fully filled, and shall be free of any surface defects.

9.4.3 The tightness of tie rods shall be proper and the tightness of the various tie rods shall be substantially the same. The tie rods shall not be welded together at their intersection points.

10 Vertical cylindrical storage tanks

10.1 General requirements

10.1.1 The seismic design of flat-bottomed welded vertical cylindrical steel storage tank with a height to diameter ratio not greater than 1.6 and a nominal capacity greater than or equal to $100m^3$ (referred to "storage tank") shall meet the requirements of this chapter.

10.1.2 The volume between the upper surface of the stored liquid and the fixed roof shall not be less than 4% of the nominal capacity of the storage tank.

10.1.3 In calculation of seismic action on storage tank, the effect of stored liquid shall be taken into account.

10.2 Natural vibration period

10.2.1 The basic natural vibration period of tank-liquid coupling vibration of storage tank may be calculated according to the following formula:

$$T_1 = K_c H_w \sqrt{\frac{R}{\delta_{1/3}}} \times 10^{-3} \tag{10.2.1}$$

Where, T_1—basic natural period of vibration of tank-liquid coupling vibration of storage tank(s);

K_c—coefficient of tank-liquid coupling vibration period, which is selected from Table 10.2.1, and the intermediate value may be calculated using interpolation method;

H_w—design highest level of liquid(mm);

R—inside radius of storage tank(mm);

$\delta_{1/3}$—nominal thickness of tank shell at 1/3 height apart from bottom plate minus negative deviation thickness of steel plate or actual thickness(mm).

Table 10.2.1 Coefficient of tank-liquid coupling vibration period K_c

D/H_w	0.6	1.0	1.5	2.0	2.5	3.0
K_c	0.514×10^{-3}	0.44×10^{-3}	0.425×10^{-3}	0.435×10^{-3}	0.461×10^{-3}	0.502×10^{-3}
D/H_w	3.5	4.0	4.5	5.0	5.5	6.0
K_c	0.537×10^{-3}	0.58×10^{-3}	0.62×10^{-3}	0.681×10^{-3}	0.736×10^{-3}	0.791×10^{-3}

Note: D is inside diameter of storage tank(mm).

10.2.2 The basic natural vibration period of stored liquid sloshing may be calculated according to the following formula:

$$T_w = 2\pi \sqrt{\frac{D}{3680g} \coth\left(\frac{3.68H_w}{D}\right)} \tag{10.2.2}$$

Where, T_w—basic natural period of vibration of stored liquid sloshing(s);

coth—hyperbolic cotangent function.

10.3 Horizontal seismic action and seismic effect

10.3.1 The horizontal seismic action on storage tank shall be calculated according to the following formulas:

$$F_{hq} = \eta R_E \alpha_1 Y_1 m_{eq} g \tag{10.3.1-1}$$

$$m_{eq} = m_L \varphi \tag{10.3.1-2}$$

Where, F_{hq}—design value of horizontal seismic action on storage tank(N);

R_E—adjustment coefficient of seismic action, which is determined according to Table 4.3.1-1;

α_1—horizontal seismic influence coefficient, which is determined according to Section 4.2 in this standard based on T_1 and damping ration of storage tank;

Y_1—influence coefficient of tank wall, which is taken as 1.1;

m_{eq}—equivalent mass of storage tank(kg);

m_L—mass of stored liquid(kg);

φ—dynamic liquid coefficient, which is calculated according to Article 10.3.3 in this standard.

10.3.2 The damping ratio of storage tank may be taken as 0.05, and 0.005 for sloshing liquid.

10.3.3 The dynamic liquid coefficient shall be calculated using the following equation:

1 Where the ratio of the maximum design liquid level(H_w) to inside radius of storage tank(R) is less than or equal to 1.5:

$$\varphi = \frac{\mathrm{th}\left(\sqrt{3}\,\dfrac{R}{H_w}\right)}{\dfrac{\sqrt{3}R}{H_w}} \tag{10.3.3-1}$$

Where, th—hyperbolic tangent function.

2 Where the ratio of the maximum design liquid level(H_w) to inside radius of storage tank(R) is greater than 1.5:

$$\varphi = 1 - 0.4375\,\frac{R}{H_w} \tag{10.3.3-2}$$

10.3.4 The overturning moment at bottom section of storage tank under horizontal seismic action shall be calculated according to the following formula:

$$M_E = 0.45 F_{hq} H_w \tag{10.3.4}$$

Where, M_E—overturning moment at bottom section of storage tank under horizontal seismic action (N·mm).

10.4 Allowable compression longitudinal stresses of tank shell

10.4.1 The critical longitudinal compressive stress of the first shell course of tank wall(counting from bottom to up) shall be calculated according to the following formulas:

$$\sigma_{cr} = \kappa_c E \frac{\delta_{e1}}{D_1} \tag{10.4.1-1}$$

$$\kappa_c = 0.13725\left(1 + 0.0429\sqrt{\frac{H}{\delta_{e1}}}\right)\left(1 - 0.1706\,\frac{D_1}{H}\right) \tag{10.4.1-2}$$

Where, σ_{cr}—critical longitudinal compressive stress of the first shell course(MPa);

κ_c—critical stress coefficient;

E—elastic modulus of tank wall material at design temperature(MPa);

δ_{e1}—effective thickness of first shell course(mm);

D_1—average diameter of first shell course(mm);

H—total height of tank wall(mm).

10.4.2 The allowable critical compressive stress of the first shell course shall be calculated according to the following formula:

$$[\sigma]_{cr} = \frac{\sigma_{cr}}{1.5} \quad (10.4.2)$$

Where, $[\sigma]_{cr}$—allowable critical compressive stress of the first shell course(MPa).

10.5 Seismic checking of tank shell

10.5.1 The uplift force per unit length along circumferential direction of the bottom wall of the tank shall be calculated according to the following formula:

$$F_t = \frac{4M_s}{\pi D_1^2} \quad (10.5.1)$$

Where, F_t—uplift force per unit length along perimeter of the circumferential direction of bottom wall of the tank(N/mm).

10.5.2 The resistance to uplift force per unit length along circumferential direction of the bottom wall of the tank shall be calculated according to the following formulas:

$$F_L = F_{L0} + \frac{N_1}{\pi D_1} \quad (10.5.2\text{-}1)$$

$$F_{L0} = 99\delta_{eb}\sqrt{R_{eL} H_w \rho_s} \times 10^{-3} \quad (10.5.2\text{-}2)$$

Where, F_L—resistance to uplift force per unit length along perimeter of the bottom wall of the tank (N/mm);

F_{L0}—maximum resistance to uplift force of stored liquid and bottom plate(N/mm); when it is greater than $0.02\, H_w D_1 \rho_s g \times 10^{-9}$, it is taken as $0.02\, H_w D_1 \rho_s g \times 10^{-9}$, and the width of bottom annulus from the inside shell is taken as $0.035D$;

N_1—gravitational force applied at bottom of the first shell course(N);

δ_{eb}—effective thickness of bottom annulus(mm);

R_{eL}—material yield strength of bottom annulus(MPa);

ρ_s—density of liquid(kg/m^3).

10.5.3 If the uplift force(F_t) per unit length along perimeter of the bottom wall of the tank is greater than 2 times the resistance to uplift force($2F_L$), the tank shall be anchored to the foundation.

10.5.4 The anchored tank shall comply with the following requirements:

1 The longitudinal compressive stress at bottom wall of the tank shall be calculated according to the following formulas:

$$\sigma_c = C_v \frac{N_1}{A_1} + \frac{M_s}{Z_1} \quad (10.5.4\text{-}1)$$

$$\sigma_c \leqslant [\sigma_{cr}] \quad (10.5.4\text{-}2)$$

Where, σ_c—longitudinal compressive stress at bottom wall of the tank(MPa);

C_v—influence coefficient of vertical seismic force, which is taken as 1.0 for regions where the seismic fortification intensity is 7 or 8 degree and 1.45 for regions where the seismic fortification intensity is 9 degree;

A_1—cross-sectional area of the first shell course(mm^2), which is taken as $\pi D_1 \delta_1$;

Z_1—bending section modulus of cross-section of the first shell course(mm^3), which is taken as $0.785\, D_1^2 \delta_{e1}$.

2 The tensile stress of anchor bolts shall be calculated according to the following formulas:

$$\sigma_{bt} = \frac{1}{n A_{bt}}\left(\frac{4M_s}{D_1} - N_1\right) \quad (10.5.4\text{-}3)$$

$$\sigma_{bt} \leqslant [\sigma]_{bt} \quad (10.5.4\text{-}4)$$

Where, σ_{bt}—tensile stress of anchor bolt(MPa), which is taken as 0 if the calculated value is less than 0;

n—quantity of anchor bolts;

A_{bt}—effective cross-sectional area of single anchor bolt(mm^2);

D_t—diameter of the center circle of anchor bolts(mm);

$[\sigma]_{bt}$—allowable stress (MPa) of anchor bolts, which is taken as 80% of the lower limit of the standard yield strength of anchor bolt materials.

10.5.5 The longitudinal compressive stress at the bottom wall of self-anchored tank shall meet the following requirements:

1 Where the uplift force(F_t) per unit length along perimeter of the bottom wall of the tank is less than or equal to the resistance to uplift force (F_L), it shall be calculated according to the following formula:

$$\sigma_c = C_v \frac{N_1}{A_1} + \frac{M_1}{Z_1} \qquad (10.5.5\text{-}1)$$

2 Where the uplift force (F_t) per unit length along perimeter of the bottom wall of the tank is greater than the resistance to uplift force(F_L) but less than or equal to twice the resistance to uplift force ($2F_L$), it shall be calculated according to the following formulas:

$$\sigma_c = C_v \frac{N_1}{A_1} + C_L \frac{M_1}{Z_1} \qquad (10.5.5\text{-}2)$$

$$C_L = 0.4\left(\frac{F_t}{F_L}\right)^2 - 0.7\left(\frac{F_t}{F_L}\right) + 1.3 \qquad (10.5.5\text{-}3)$$

Where, C_L—uplift influence coefficient of bottom plate.

3 The longitudinal compressive stress at bottom wall of the tank shall meet the following requirement:

$$\sigma_c \leqslant [\sigma_{cr}] \qquad (10.5.5\text{-}4)$$

4 Where the longitudinal compressive stress (σ_c) at the bottom wall of the tank is greater than the allowable critical compressive stress ($[\sigma_{cr}]$), one or more of the following measures may be taken and the calculation in Items 1 and 2 of this Article shall be repeated until the relevant requirements are met:

1) Reduce the height/diameter ratio of tank.

2) Increase the thickness of the first shell course.

3) Increase the thickness of the bottom annular plate.

4) mount the tank to the foundation.

10.5.6 Where the thickness of the first shell course obtained from seismic checking in this section is greater than the thickness obtained from static head of liquid calculation (taking no account of corrosion allowance), the thickness of each of other shell course shall also be determined through seismic checking, based on the thickness obtained from static liquid pressure-based calculation.

10.6 Liquid sloshing height

10.6.1 The liquid sloshing wave height inside the tank under horizontal seismic action shall be calculated according to the following formula:

$$h_v = \bar{\eta} K_s \alpha_1 R \qquad (10.6.1\text{-}1)$$

$$K_s = 3.03629 - 0.67886 \times T_w + 0.06602 \times T_w^2 - 0.00197 \times T_w^3 \qquad (10.6.1\text{-}2)$$

Where, h_v—liquid sloshing wave height inside the tank(mm);

$\bar{\eta}$—tank type coefficient, which is taken as 0.85 for floating roof tank and internal floating roof tank, and 1.0 for fixed roof tank;

K_v—adjustment coefficient;

α_v—horizontal seismic influence coefficient, which shall be determined based on T_w and liquid sloshing damping ratio according to the requirement of Section 4.2 in this standard in respect of precautionary earthquake.

10.6.2 In the case of containing flammable or toxic liquid, for floating roof tanks, the distance from the upper surface of floating roof to the top of tank shell shall be greater than the sloshing height; for fixed roof tanks, the distance from the liquid surface to the top of tank shell shall be greater than the sloshing height.

10.7 Details of seismic design

10.7.1 For floating roof tanks containing flammable liquid, the guiding device and rotating stairs shall have good contact and shall be connected reliably, and soft sealing material should be filled between the floating roof and tank wall.

10.7.2 For tanks anchored with bolts, the distance between bolts shall not be greater than 2m if the diameter of the tank is less than 15m and shall not be greater than 3m if the diameter of the tank is greater than or equal to 15m. The diameter of the bolts shall not be less than M24, and the nuts shall be anti-loosening.

11 Tubular heater

11.1 General requirements

11.1.1 Except for ethylene cracking furnace, the seismic design of the tubular heater, auxiliary combustion chamber, sulfur plant heater, and ducts of air preheat system and stack shall comply with the requirements of this chapter.

11.1.2 The seismic action on the heater structure shall comply with the following requirements:

1 For the framework structures of box heater and convection section of cylindrical heater, the horizontal seismic action shall be calculated in two principal direction on the horizontal plane, and seismic checking shall be carried out. The horizontal seismic action in each direction shall be resisted by the lateral force resisting members in that direction.

2 For horizontal heater, it is allowed to calculate only the lateral horizontal seismic action on the heater body, and seismic checking shall be carried out.

3 For stacks mounted on ground, where the design basic acceleration of ground motion is 0.20g-0.40g or the seismic fortification intensity is 8 or 9 degree, vertical seismic action shall be calculated, and combined with the horizontal seismic action according to the current national standard GB 50011 *Code for Seismic Design of Buildings*, and seismic checking shall be carried out.

4 For heater higher than 30m (including the height of stack on the top of the heater) in regions where the design basic seismic acceleration value is 0.4g or the seismic precautionary intensity is 9 degree, vertical seismic action shall be calculated and combined with the horizontal seismic action according to the current national standard GB 50011 *Code for Seismic Design of Buildings*, and seismic checking shall be carried out.

11.2 Natural vibration period

11.2.1 The heater may be simplified as a multiple- mass points structure system. When the matrix iteration method is used to calculate the natural vibration period of the heater, the flexibility matrix elements may be calculated according to Appendix D in this standard.

11.2.2 For the cylindrical heater with a height H less than or equal to 35m, its basic vibration natural period may be determined according to the following requirements:

1 The basic natural vibration period of radiant type cylindrical heater (Figure 11.2.2-1) may be calculated according to the following formula:

$$T_1 = 0.0268 + 0.0444\frac{H_s}{\sqrt{D_2}} \tag{11.2.2-1}$$

Where, T_1—basic natural vibration period (s);

H_s—sum of height of floor column, cylinder and conic section of heater (m);

D_2—outside diameter of cylinder of radiant section (m).

2 The basic natural vibration period of radiant-convection type cylindrical heater (Figure 11.2.2-2) may be calculated according to the following formula:

$$T_1 = 0.2505 + 0.976\times10^{-3}\left(\frac{H_1^2}{D_2}+\frac{h_3^2}{D_3}\right) \tag{11.2.2-2}$$

Where, H_1—sum of height of floor column, radiant section and convection section of heater(m);

h_4—height of stack(m);

D_3—outside diameter of stack(m).

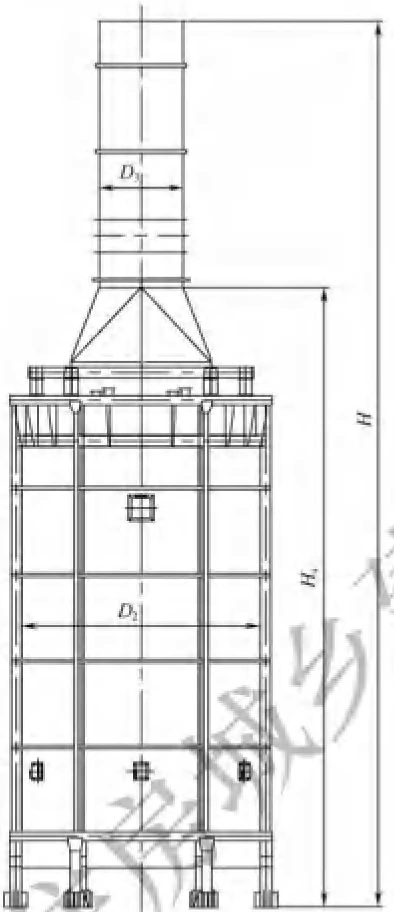
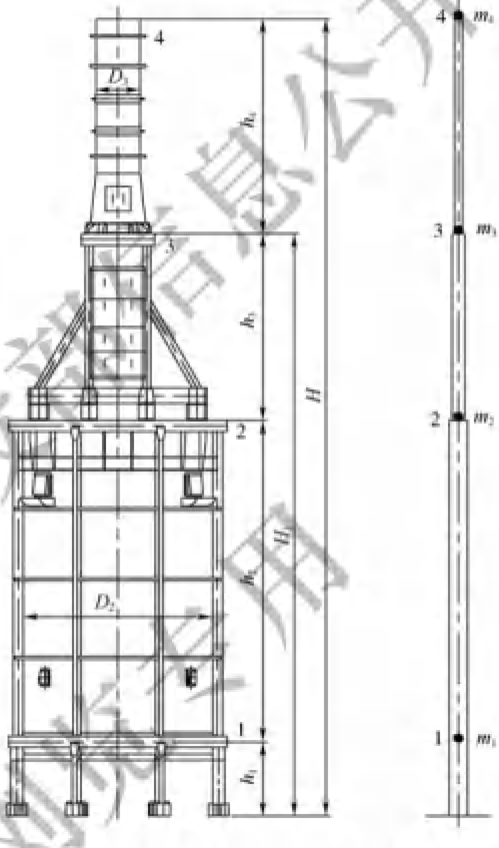


Figure 11.2.2-1 Diagram of radiant cylindrical heater



(a) Heater body (b) Schematic diagram for calculation

Figure 11.2.2-2 Diagram of radiant-convection cylindrical heater

11.2.3 For box heater with a height H less than or equal to 40m (Figure 11.2.3-1 and Figure 11.2.3-2), the basic vibration natural period may be calculated according to the following formula:

$$T_1 = 0.2749 + 0.02924 \frac{H_L}{\sqrt[3]{b}} \tag{11.2.3}$$

Where, H_L—calculated height of heater frame(m), if the side frame of radiant section does not extend to convection section, the distance from the centroid of convection section to lower surface of frame column base plate is taken;

b—span of heater frame column centerline(m); if the frame comprises multiple columns, value b is the distance of centerline of the outermost span.

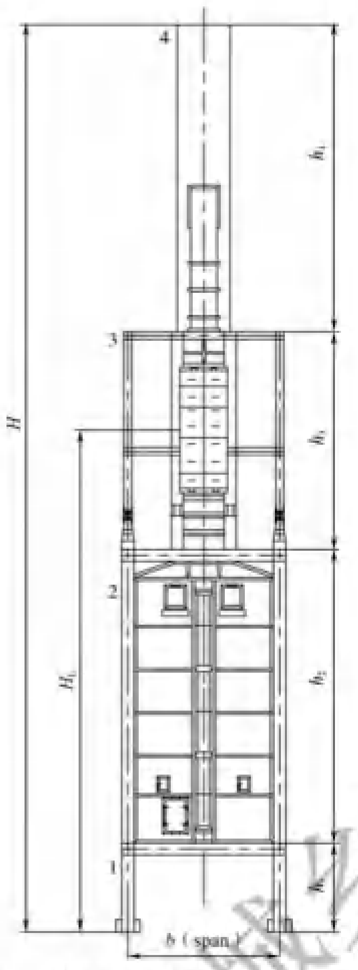


Figure 11.2.3-1 Diagram of box heater

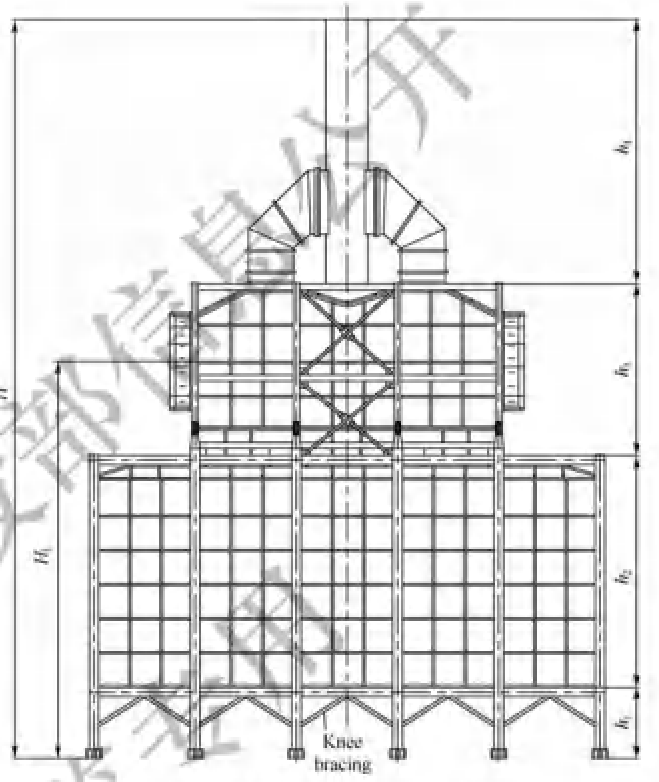


Figure 11.2.3-2 Diagram of vertical heater with convection section in the middle frame

11.2.4 The natural vibration period of stack mounted on ground may be determined according to the following requirements:

1 The basic natural vibration period of straight cylinder type stack with constant cross section may be calculated according to the following formula:

$$T_1 = 1.79 H_e \sqrt{\frac{m_e H_e}{E^t I}} \quad (11.2.4\text{-}1)$$

Where, H_e—calculated height of stack(m), from lower surface of base plate of anchor bolts to top surface;

m_e—mass of stack(kg); if the lining is connected to the stack shell, the mass of lining is included;

E^t—elastic modulus at design temperature(Pa);

I—moment of inertia of stack cross-section(m^4).

2 The basic natural vibration period of cone stack (Figure 11.2.4) may be calculated according to the following formula:

$$T_1 = \lambda H_e^2 \sqrt{\frac{A\rho}{E^t I_1}} \quad (11.2.4\text{-}2)$$

Where, λ—cone height coefficient, which is consulted from Table 11.2.4 based on the ratio of H_0/H_{1e};

A—bottom cross-sectional area of the stack (m^2);

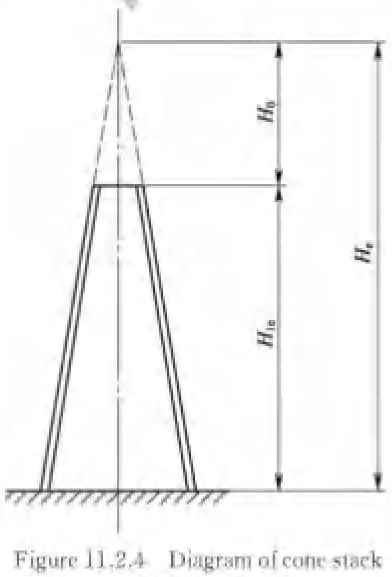


Figure 11.2.4 Diagram of cone stack

H_0—extension height of cone stack(m);

H_{1e}—height of stack(m)

ρ—density of stack(kg/m^3); if lining is connected to the stack shell, the combination density of lining and stack is taken;

I_0—moment of inertia of bottom cross-section of the stack(m^4).

Table 11.2.4 Cone height coefficient λ

$\frac{H_c}{H_L}$	0.4	0.6	0.8	1.0
λ	1.29	1.5	1.7	1.79

3 The variable cross-section stack may be simplified into a multiple-mass points structural system to calculate its natural vibration period.

11.3 Seismic action and seismic checking

11.3.1 The seismic fortification level of heaters shall be in accordance with Category Ⅱ of current national standard GB 50453 *Standard for Classification of Seismic Protection of Buildings and Special Structures in Petrochemical Engineering*.

11.3.2 The seismic action and seismic checking of heaters shall comply with the requirements of GB 50011 *Code for Seismic Design of Buildings*.

11.3.3 The damping ratio of cylindrical heater structure may be taken as 0.03, and that of box heater structure may be taken as 0.04.

11.3.4 The seismic action on heater may be calculated using the following methods:

1 For box heater with a height less than or equal to 40m, including the height of stack at the top of the heater, base shear method may be used.

2 For tubular heaters except for those described in Item 1 of this article, mode-superposition response spectrum method may be used.

3 For horizontal heater, base shear method may be used. The seismic influence coefficient may be taken as the maximum value.

11.3.5 The representative value of the gravity load used for calculation of seismic action shall be taken as the sum of standard value of self-weight of the structure and accessories and the combination of various variable loads. The combination coefficient of live loads on the platform shall be taken as 0.5.

11.3.6 The horizontal seismic action on the stack at top of box heater may be calculated using base shear method. The seismic effect on the stack shall be multiplied by an amplification factor 2.0. The amplified seismic effect may only be used to calculate the thickness of the stack and its connected part. In calculation of seismic action on the heater structure, the mass of stack on the top of the heaters may be regarded as a concentrated mass on the top surface of the heater.

11.3.7 The horizontal seismic action on stack mounted on ground may be calculated using base shear method if the height is less than or equal to 40m, and mode superposition response spectrum method may be used if the height is greater than 40m.

11.3.8 The vertical seismic action and seismic checking of floor stack mounted on ground shall comply with the requirements of the current national standard GB 50051 *Code for Design of Chimneys*.

11.3.9 The seismic action on the auxiliary equipment and air preheat system of heater may be calculated using the following methods:

1 For steel frame mounted on ground supporting the air preheater, base shear method may be used.

2 For overhead ducts and its supports, only the horizontal seismic action perpendicular to the direction of length of ducts is calculated. The maximum value of the seismic influence coefficient may be taken according to Article 4.2.1 in this standard.

11.3.10 The seismic deformation of heater under the frequent seismic action shall be checked. The allowable deflection of bending members shall comply with the requirements in Table 11.3.10.

Table 11.3.10 Allowable deflection of bending members

Name of member	Allowable deflection
Beam of hanging tube	$L/400$
Beam of main frame	$L/400$
Bottom beam of convection section of cylindrical heater	$L/450$
Base beam of stack	$L/400$
Floor Beam of heater	$L/360$
Base beam of fan on the top of heater	$L/400$
Other beams	$L/250$
Purlins of operating shed	$L/200$

Note: L is the span of bending member, for cantilever beam, take 2 times the overhang length.

11.3.11 The allowable displacement at the top of frame columns of the heaters shall be less than 1/450 of total length of the columns.

11.4 Details of seismic design

11.4.1 The box heater shall comply with the following requirements:

1 The beams at top and bottom of side walls of heater frame and the crossbeam of the variable cross-section part of heater frame column should be constructed of hot-rolled H-shaped steel which should be sized not less than H250×125 in regions where the seismic fortification intensity is 7 degree, H300×150 in regions where the seismic fortification intensity is 8 degree and H350×175 in regions where the seismic fortification intensity is 9 degree.

2 The plane of heater top shall be provided with structural diagonal bracing, which should be sized not less than angle steel 75×6 in regions where the seismic fortification intensity is 7 degree, angle steel 90×8 in regions where the seismic fortification intensity is 8 degree and angle steel 110×10 in regions where the seismic fortification intensity is 9 degree. If double-leg angle steel is used, the size should not be less than angle steel 63×6 in regions where the seismic fortification intensity is 7 degree, angle steel 75×6 in regions where the seismic fortification intensity is 8 degree and angle steel 90×8 in regions where the seismic fortification intensity is 9 degree.

3 Where a stack is provided on the top of the heater, diagonal bracings shall be provided between two columns supporting the stack. The angle between the diagonal bracings and columns should be 30° to 60°.

4 Rigid connection shall be used between the columns of heater frame and columns supporting the convection section.

5 Rigid connection shall be used at both ends of base beam supporting the stack on the top of the heater.

6 Gradual transition section shall be provided at connections of frame columns with different

section.

7 Knee bracings should be provided between floor columns of side walls of heater frame (Figure 11.2.3-2).

11.4.2 The cylindrical heater shall comply with the following requirements:

1 The height of convection section should not be greater than that of radiation section.

2 The structural members of convection section shall be arranged symmetrically. Where the height of convection sectionis is greater than 4m, diagonal bracings should be provided symmetrically on the side of frame columns of the convection section (Figure 11.4.2).

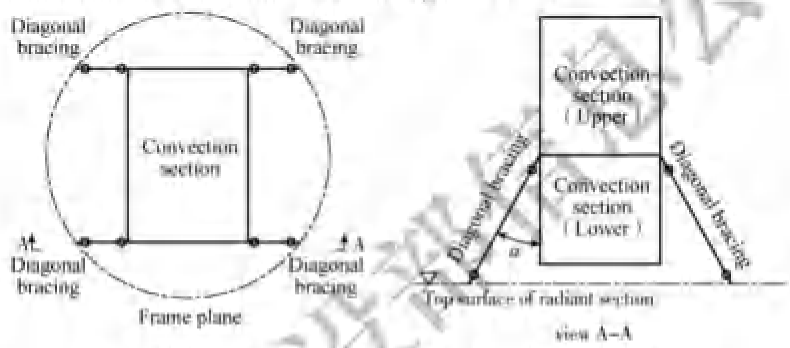


Figure 11.4.2 Diagram of diagonal bracing of convection section

3 Where a straight stack is provided on the top of the convection section, the top surface of the convection section shall be provided with horizontal bracings and the supporting members size shall not be less than angle steel 63×6.

4 Where the base of the stack on the top of the convection sectionis supported by a single beam the beam ends shall be rigidly connected, and the size should not be less than H250×125 in regions where the seismic fortification intensity is 7 degree, H300×150 in regions where the seismic fortification intensity is 8 degree and H350×175 in regions where the seismic fortification intensity is 9 degree.

5 Where the design basic acceleration of ground motion is 0.10g to 0.40g or the seismic fortification intensity is 7 degree to 9 degree, and the radiant tubes are supported on the upper part of the cylinder, downward longitudinal stiffener shall be evenly provided along the ring beam at the top of the cylinder, and the spacing between them should be 0.6m to 1.3m.

6 Where the quantity of heater floor columns are less than 8, the pedestal shall be fixedly connected to the foundation. The pedestal shall be in the form of raised platform base.

7 Where the diameter of cylinder of the radiant section is greater than 3.8m and the columns of the convection section is not coincident with the columns of the radiant section, hollow composite section should be adopted for the ring beam at the top and bottom of the radiant section.

11.4.3 The horizontal heater shall comply with the following requirements:

1 The thickness of the cylinder should not be less than 10mm.

2 The thickness and width of saddle support base plate supporting the cylinder shall not be less than 12mm and 200mm, respectively. The thickness of vertical plate of saddle support shall not be less than 12mm and the thickness of ribs shall not be less than 10mm.

3 The quantity of anchor bolts for the fixed support shall not be less than 2, and the nuts shall be anti-loosening.

4 Measures shall be taken for the sliding support to limit lateral displacement of horizontal heater.

11.4.4 The anchor bolts of heater shall not be less than M24, the nuts shall be anti-loosening, and the thickness of pedestal base plate shall not be less than 14mm.

11.4.5 Where flanged connection is used for the base of stack at the top of heater, the size of connecting bolts shall not be less than M16 and the spacing of bolts shall not be more than 250 mm. Where raised platform base connection is used, the size of connecting bolts shall not be less than M24, the quantity of bolts shall not be less than 8. The nuts shall be anti-loosening.

11.4.6 The welded joints of heater frame members shall not be located in the maximum stress area where plastic hinges may occur.

11.4.7 The overhead flue ducts shall comply with the following requirements:

1 The thickness of the flue duct plate shall not be less than 6mm.

2 Where temperature compensation is required for socket flue ducts, the expansion joints shall be determined through calculation and expansion gaps shall be reserved.

3 Bearing structures shall be provided at compensation joints of socket flue ducts.

4 Limiting devices shall be provided at supports on either side of flue ducts. The limiting plates shall be parallel to the flue ducts and should be 30mm to 50mm apart from the outer wall of the duct.

11.4.8 The thickness of the ring plate of stack mounted on ground shall not be less than 14mm, and anchor bolt chair shall be provided at bottom. The size of anchor bolts shall not be less than M24, and the quantity of anchor bolts shall not be less than 8. The nuts shall be provided with anti-loosening features.

11.4.9 The connection between beams and columns should be adopted the column-penetration type.

11.4.10 Where beams are rigidly connected with columns, the connection between the flange and web plates of welded H-shaped columns or wallboards of box column shall be welded with full penetration.

Appendix A Horizontal seismic action of on-framework equipment

A.0.1 The schematic diagram for calculation of multi-floor framework supporting the equipment can be shown in Figure 4.3.1, where m_i is the mass of the i^{th}-floor framework (including the mass of the on-framework equipment), and h_i is the height from the i^{th}- floor framework to the ground surface.

A.0.2 Given that the parameters of framework which supports the equipment and the ratio between the mass of the framework and that of the equipment is greater than or equal to 2, the dynamic amplification factor of the framework floor where the equipment is located may be selected as shown in Figure A.0.2. The horizontal seismic action on the on-framework equipment can be calculated as follows:

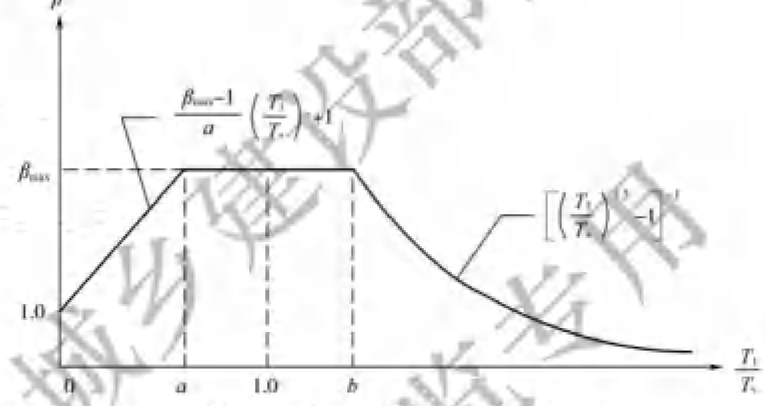


Figure A.0.2 Diagram of dynamic amplification factor of framework

T_1—basic natural vibration period(s) of equipment; T_c—basic natural vibration period of (s) of framework that supports the equipment;

a, b —left and right boundary of quasi-resonance region, respectively

1 The design value of horizontal seismic action on the equipment on the i^{th} floor framework shall be calculated according to the following formulas:

$$F_{hsi} = \eta R_E \alpha_{si} m_{eq} g \quad (A.0.2\text{-}1)$$

$$\alpha_{si} = \bar{\beta}_{max} \alpha_{ui} \quad (A.0.2\text{-}2)$$

$$\alpha_{ui} = \frac{F_i}{m_i g} \quad (A.0.2\text{-}3)$$

$$\bar{\beta}_{max} = \psi \beta_{max} \quad (A.0.2\text{-}4)$$

Where, F_{hsi}—design value of horizontal seismic action on the equipment on the i^{th}-floor framework (N), which shall not be less than the calculation value of horizontal seismic action on the equipment when mounted on ground;

α_{si}—influence coefficient of horizontal seismic action on the equipment on the i^{th}-floor framework;

m_{eq}—equivalent mass of equipment on the i^{th}-floor framework (kg);

$\bar{\beta}_{max}$—maximum value of dynamic amplification factor of the framework after correction;

F_i—horizontal seismic action on the i^{th}-floor framework (N);

ψ—feedback influence coefficient, which is selected from Table A.0.2-1;

β_{max}—maximum value of dynamic amplification factor of the framework before correction, which is selected from Table A.0.2-2.

Table A.0.2-1 Feedback influence coefficient ψ

m_s/m_t	Damping ratio ζ					
	0.1	0.07	0.05	0.02	0.01	0.005
2	0.50	0.42	0.37	0.29	0.28	0.27
10	0.68	0.58	0.51	0.38	0.35	0.34
50	0.87	0.81	0.76	0.67	0.62	0.60
100	0.93	0.91	0.90	0.80	0.80	0.80
≥500	1.00	1.00	1.00	1.00	1.00	1.00

Note: The intermediate value can be obtained using linear interpolation method. m_s is mass of the framework (including the mass of other equipment and accessories on the framework), and m_t is mass of the calculated equipment.

Table A.0.2-2 Maximum value of dynamic amplification factor of the framework before correction β_{max}

Damping ratio ζ	0.1	0.07	0.05	0.02	0.01	0.005
β_{max}	3.5	4.6	5.5	8.5	10.5	12.5

Note: The intermediate value can be obtained using linear interpolation method.

2 In determining T_1 value, the framework that supports the equipment shall be regarded as the rigid foundation of the equipment.

3 In determining T_s value, the mass shall include the on-framework equipment and other accessories. If it is impossible to obtain an accurate value, T_s may be calculated according to Article A.0.4 in this standard.

A.0.3 The left and right boundary of quasi-resonance region may be calculated according to the following formulas:

$$a = \left(1 - \frac{1}{\beta_{max} - 0.3}\right)^{1/1.3} \quad (A.0.3\text{-}1)$$

$$b = \left(1 + \frac{1}{\beta_{max}}\right)^{1/1.3} \quad (A.0.3\text{-}2)$$

A.0.4 The basic natural vibration period of the framework that supports the equipment may be calcuated using the following simplified method:

1 The basic natural vibration period of steel framework may be calculated according to the following formulas:

$$T_s = 3H_s \times 10^{-3} \quad (A.0.4\text{-}1)$$

Where, T_s—basic natural vibration period of framework (s);

H_s—total height of framework (mm).

2 The basic natural vibration period of reinforced concrete framework may be calculated according to the following formula:

$$T_s = 2H_s \times 10^{-3} \quad (A.0.4\text{-}2)$$

Appendix B Seismic checking of vertical vessels supported by legs

B.0.1 The horizontal reaction force of legs shall be determined according to the following formula:

$$R_l = \frac{F_Z}{n} + \frac{F_{ek}}{n} \tag{B.0.1}$$

Where, R_l—horizontal reaction force of single leg(N);

F_Z—horizontal load on equipment(N), which is the sum of all horizontal loads except for horizontal seismic action;

F_{ek}—design value of horizontal seismic action on the equipment(N);

n—quantity of legs of the equipment.

B.0.2 The vertical reaction force of single leg shall be determined according to the following formula:

$$F_l = \pm\left(\frac{4M_t}{nD_b} + \frac{4M_e}{nD_b}\right) - \frac{W}{n} \tag{B.0.2}$$

Where, F_l—vertical reaction force of single leg(N);

M_t—overturning moment caused by design value of horizontal seismic action(N·mm);

M_e—overturning moments(N·mm), moments caused by horizontal loads except for horizontal seismic action, moments caused by eccentric mass, moments caused by piping and other bending moments;

D_b—diameter of center circle of anchor bolts(mm);

W—vertical loads(N), including self-weight of equipment, piping load and other vertical loads.

B.0.3 The seismic checking of cross-section of leg shall comply with the following requirements:

1 The bending stress of legs may be calculated according to the following formula:

$$\sigma_b = \frac{R_l L_c + F_l e}{Z} \tag{B.0.3-1}$$

2 The compressive stress of leg may be calculated according to the following formula:

$$\sigma_c = \frac{F_l}{A_l} \tag{B.0.3-2}$$

Where, σ_b—bending stress of leg(MPa);

R_l—horizontal reaction force of leg(N);

L_c—calculated height of leg, which is the distance from bottom surface of foundation plate to center of weld joints between legs and shell(mm);

F_l—vertical reaction force of leg(N);

e—distance from outside surface of equipment to centroid of leg(Figure B.0.3);

Z—minimum bending section modulus of leg(mm^3);

σ_c—compressive stress of leg(MPa);

A_l—cross-sectional area of leg(mm^2).

3 The allowable critical compressive stress of leg may be calculated according to the following requirements:

1) If $\lambda \leqslant \bar{\lambda}$, the following formula may be applied:

$$[\sigma]_{cr} = \frac{\left[1 - 0.4\left(\frac{\lambda}{\bar{\lambda}}\right)^2\right][\sigma]}{\quad} \tag{B.0.3-3}$$

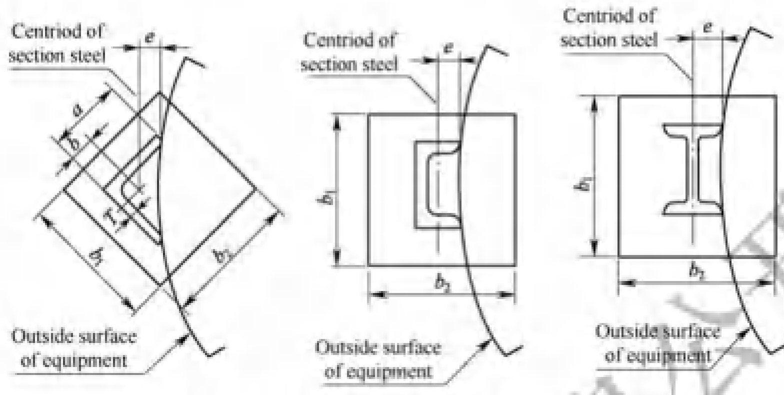


Figure B.0.3 Diagram of leg and base plate

2) If $\lambda > \bar{\lambda}$, the following formulas may be applied:

$$[\sigma]_{cr} = \frac{0.277[\sigma]}{\left(\frac{\lambda}{\bar{\lambda}}\right)^2} \tag{B.0.3-4}$$

$$\lambda = \frac{0.7L}{i} \tag{B.0.3-5}$$

$$\bar{\lambda} = \sqrt{\frac{\pi^2 E}{0.6[\sigma]}} \tag{B.0.3-6}$$

$$\nu = \frac{3}{2} + \frac{2}{3}\left(\frac{\lambda}{\bar{\lambda}}\right)^2 \tag{B.0.3-7}$$

Where, λ—effective slenderness ratio of leg;

$\bar{\lambda}$—critical slenderness ratio of leg;

$[\sigma]_{cr}$—allowable critical compressive stress of leg(MPa);

$[\sigma]$—allowable seismic stress of material of leg(MPa), which is determined according to Article 4.7.2 in this standard;

ν—a coefficient determined by λ and $\bar{\lambda}$;

i—minimum gyration radius of cross-section of single leg(mm);

E—elastic modulus of material of leg(MPa).

4 The seismic checking of cross-section of leg shall comply with the following formula:

$$\frac{\sigma_c}{[\sigma]_{cr}} + \frac{\sigma_b}{[\sigma]} \leqslant 1 \tag{B.0.3-8}$$

Where, $[\sigma]$—allowable seismic stress of legs(MPa), which is determined according to Article 4.7.2 in this standard.

B.0.4 The seismic checking of weld joint between leg and cylinder shall be calculated according to the following formulas:

1 The shear stress of weld may be calculated from the following formulas:

$$\tau = \frac{F_1}{A_f} \tag{B.0.4-1}$$

$$\tau \leqslant [\tau] \tag{B.0.4-2}$$

Where, τ—shear stress of weld(MPa);

A_f—shear area of weld(mm^2);

$[\tau]$—allowable shear stress of weld(MPa), which is determined according to Article 4.7.2 in this standard.

2 The bending stress of weld may be calculated according to the following formulas:

$$\sigma = \frac{R_l L_c}{Z_l} \tag{B.0.4-3}$$

$$\sigma \leqslant [\sigma] \tag{B.0.4-4}$$

Where, σ—bending stress of weld(MPa);

Z_l—bending section modulus of weld(mm^3);

$[\sigma]$—allowable seismic stress of weld(MPa), which is determined according to Article 4.7.2 in this standard.

B.0.5 The seismic checking of anchor bolt shall meet the following requirements:

1 If $F_l>0$, the tensile stress of anchor bolt shall be checked according to the following formulas:

$$\sigma_b = \frac{F_l}{n_b A_b} \tag{B.0.5-1}$$

$$\sigma_b \leqslant [\sigma]_b \tag{B.0.5-2}$$

Where, σ_b—tensile stress of anchor bolt(MPa);

n_b—quantity of anchor bolts for single leg;

A_b—effective cross-sectional area of anchor bolt(mm^2);

$[\sigma]_b$—allowable seismic stress of anchor bolt(MPa), which is determined according to Article 4.7.2 in this standard.

2 The shear stress of anchor bolt may be calculated according to the following formulas:

$$\tau_b = \frac{R_L}{n_b A_b} \tag{B.0.5-3}$$

$$\tau_b \leqslant [\tau]_b \tag{B.0.5-4}$$

Where, τ_b—shear stress of anchor bolt(MPa);

$[\tau]_b$—allowable seismic shear stress of anchor bolt (MPa), which is determined according to Article 4.7.2 in this standard.

B.0.6 The thickness of base plate of legs may be calculated according to the following requirements:

1 The compressive stress of base plate of leg may be calculated according to the following formula:

$$\sigma_{cb} = \frac{F_l}{b_1 b_2} \tag{B.0.6-1}$$

Where, σ_{cb}—compressive stress of base pate of leg(MPa);

b_1—length of base plate of leg(mm);

b_2—width of base plate of leg(mm).

2 The thickness of base plate of leg may be calculated according to the following formula:

$$\delta_b = B_l \sqrt{\frac{3\sigma_{cb}}{[\sigma]}} + C_2 \tag{B.0.6-2}$$

Where, δ_b—thickness of base plate of leg(mm);

B_l—maximum distance from leg to edge of base plate(mm);

$[\sigma]$—allowable seismic stress of base plate of leg(MPa), which is determined according to Article 4.7.2 in this standard;

C_2—corrosion allowance of base plate of leg(mm).

Appendix C　Seismic checking of vertical vessels supported by lugs

C.0.1　The reaction force of lug caused by horizontal loads(Figure C.0.1)shall be calculated from the following equation:

$$F_r = F_t = \pm\left(\frac{F_h}{n} + \frac{F_d}{n}\right) \tag{C.0.1}$$

Where, F_r—radial reaction force on lug of equipment caused by horizontal loads(N);

F_t—circumferential reaction force on lugs of equipment caused by horizontal loads(N);

F_h—horizontal load on equipment (N), which is a combination of horizontal loads except for horizontal seismic action;

F_d—design value of horizontal seismic action on equipment(N);

n—quantity of lugs of equipment.

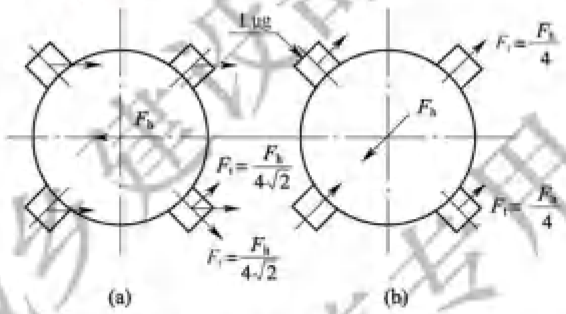


Figure C.0.1　Diagram of reaction force at lugs caused by horizontal loads

C.0.2　The vertical reaction force of the lug caused by bending moments and vertical loads shall be calculated according to the following formula:

$$F_1 = \pm\left(\frac{4M_1}{nD_b} + \frac{4M_2}{nD_b}\right) - \frac{W}{n} \tag{C.0.2}$$

Where, F_1—vertical reaction force of lug(N);

M_1—overturning moment caused by horizontal design seismic action(N·mm);

M_2—overturning moment (N·mm), moments caused by other horizontal loads except for horizontal seismic action, moments caused by eccentric mass, moments caused by piping and other bending moments;

D_b—diameter of center circle of anchor bolts of equipment(mm);

W—vertical loads(N), including weight of equipment, piping load and other vertical loads.

C.0.3　The stress of lug may be calculated according to the following formula:

$$\sigma = \frac{F_1 l}{Z_1} + \frac{F_t l}{Z_1} + \frac{F_r}{A_1} \tag{C.0.3}$$

Where, σ—stress of lug(MPa);

F_1—vertical reaction force of lug(N), which is calculated according to the Formula C.0.2;

F_t—circumferential reaction force of lug caused by horizontal loads (N), which is calculated according to the Formula C.0.1;

F_r—radial reaction force of lug caused by horizontal loads(N), which is calculated according to the Formula C.0.1;

l—distance from outside surface of equipment body to point of reaction force(mm);

Z_l—axial bending modulus of lug with respect to equipment(mm^3);

Z_r—circumferential bending modulus of lug with respect to equipment(mm^3);

A_l—cross-sectional area of lug(mm^2).

C.0.4 The stress in weld joint of lug shall meet the following requirements:

1 The tensile stress may be calculated according to the following formulas:

$$\sigma = \frac{F_r}{A'_l} \tag{C.0.4-1}$$

$$\sigma \leqslant [\sigma] \tag{C.0.4-2}$$

2 The shear stress may be calculated according to the following formulas:

$$\tau = \frac{\sqrt{F_r^2 + F_l^2}}{A_l} \tag{C.0.4-3}$$

$$\tau \leqslant [\tau] \tag{C.0.4-4}$$

Where, σ—tensile stress in weld(MPa);

$[\sigma]$—allowable seismic tensile stress of weld(MPa);

τ—shear stress in weld(MPa);

$[\tau]$—allowable seismic shear stress of weld(MPa);

A_l—cross-sectional area of fillet of weld(mm^2);

A'_l—cross-sectional area of weld(mm^2).

C.0.5 The seismic checking of anchor bolt shall meet the following requirements:

1 If $F_l > 0$, the tensile stress of anchor bolt shall be calculated according to the following formulas:

$$\sigma_b = \frac{F_l}{n_b A_b} \tag{C.0.5-1}$$

$$\sigma_b \leqslant [\sigma]_b \tag{C.0.5-2}$$

Where, σ_b—tensile stress of anchor bolt(MPa);

n_b—quantity of anchor bolts for single lug;

A_b—effective cross-sectional area of single anchor bolt(mm^2);

$[\sigma]_b$—allowable seismic stress of anchor bolt(MPa), which is determined according to Article 4.7.2 in this standard.

2 The shear stress of anchor bolt may be calculated according to the following formulas:

$$\tau_b = \frac{F_r}{n_b A_b} \tag{C.0.5-3}$$

$$\tau_b \leqslant [\tau]_b \tag{C.0.5-4}$$

Where, τ_b—shear stress of anchor bolt(MPa);

$[\tau]_b$—allowable seismic shear stress of anchor bolts (MPa), which is determined according to Article 4.7.2 in this standard.

Appendix D Calculation of flexible matrix elements

D.0.1 The flexible matrix elements shall be determined according to the following requirements(Figure D.0.1).

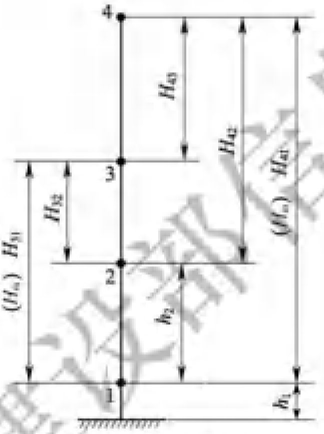


Figure D.0.1 Diagram of calculation model of multiple-mass point system

1 The static displacement may be calcuated according to the following formula:

$$\delta_{ji} = \delta_{ij} = \sum_{n=1}^{i} \frac{h_n}{EI_n}\left[H_{jn}H_{in} + \frac{1}{2}h_n(H_{jn} + H_{in}) + \frac{1}{3}h_n^2\right] + \sum_{n=1}^{i} \frac{K_n h_n}{GA_n}(j = 1,2,3\cdots, i = 1,2,3\cdots, i \leqslant j) \tag{D.0.1}$$

Where, δ_{ji}, δ_{ij}—horizontal displacement of mass point $j(i)$ caused by unit force acting on mass point $i(j)$ (mm/N);

j, i—sequential number of mass points;

h_n—distance between mass point n and mass point n-1(mm);

E—elastic modulus of material(MPa);

I_n—moment of inertia(mm^4);

H_{jn}, H_{in}—height difference between mass point n and mass point j, and between mass point n and mass point i(mm);

K_n—shape coefficient of shear section;

G—shear modulus of material(MPa);

A_n—calculated cross-sectional area(mm^2).

2 For radiant-convection cylindrical heater, I_n, A_n and K_n may be calculated according to Table D.0.1-1.

3 For radiant-convection cylindrical heater, only the horizontal static displacement at the heater base, top of radiant section, top of convection section and top of stack may be calculated.

4 After the static displacement is obtained, substitute it into the characteristic equation to solve the dynamic characteristics of the heater. The mass of mass point "m_i" may be calculated according to Table D.0.1-2. The first two vibration modes may be taken.

Table D.0.1-1 Geometrical features of radiant-convection cylindrical heater

Part	Cross-sectional area(mm^2)	Moment of inertia(mm^4)	Shape coefficient of shear section
Floor column	$A_1 = nA_{01}$	$I_1 = \frac{1}{2}nA_{01}\left(\frac{D_1}{2}\right)^2$	$K_1 = \frac{\text{Full cross-sectional area}}{\text{Cross-sectional area of web plate}}$
Radiant section	$A_2 = nA_{02} + \pi D_2 t_2$	$I_2 = \frac{1}{2}nA_{02}\left(\frac{D_2}{2}+\frac{d_2}{2}\right)^2 + 0.393D_2^3 t_2$	$K_2=3$
Convection section	$A_3 = nA_{03} + [ab-(a-2t_3)(b-2t_3)]$	$I_3 = nA_{03}\left(\frac{b}{2}\right)^2 + \frac{1}{12}[ab^3-(a-2t_3)(b-2t_3)^3]$	$K_3=3$
Stack	$A_4 = \pi D_4 t_4$	$I_4 = 0.393D_4^3 t_4$	$K_4=0$

Note: n—quantity of columns;

A_{01}—cross-sectional area of single column(mm^2);

D_1—center circle diameter of floor columns(mm);

A_{02}—cross-sectional area of single cylinder column of radiant section(mm^2);

D_2—cylinder diameter of radiant section(mm);

t_2—cylinder thickness of radiant section(mm);

d_2—height of section of single cylinder column of radiat section(mm);

A_{03}—cross-sectional area of single column of convection section(mm^2);

a—length of long side of convect section plate(mm);

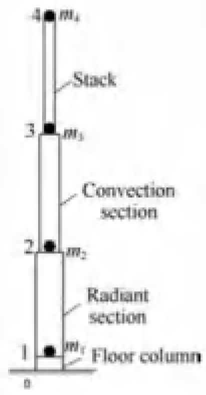
b—length of short side of convect section plate(mm);

t_3—thickness of convect section plate(mm);

D_4—diameter of stack shell(mm);

t_4—thickness of stack shell(mm).

Table D.0.1-2 Mass of mass point

Mass point	Schematic diagram	m_i	
		Suspension tube	Seat tube
4		$m_4=0.25Q_4$	$m_4=0.25Q_4$
3		$m_3=0.75Q_4+0.5Q_3$	$m_3=0.75Q_4+0.5Q_3$
2		$m_2=0.5(Q_2+Q_3)+Q'_2$	$m_2=0.5(Q_2+Q_3)$
1		$m_1=0.5Q_2+Q_1$	$m_1=0.5Q_2+Q_1+Q'_2$

Note: Q_4—mass of stack(kg);

Q_3—mass of convect section(including water filled in tubes and preheater)(kg);

Q_2—mass of radiant section(kg);

Q'_2—mass of tubes of radiant section(including water filled in tubes)(kg);

Q_1—mass of heater base and floor columns(kg).

D.0.2 The static displacement of box heater may be calculated using interlayer stiffness method. After the static displacement is obtained, substitute it together into mass "m_i" of mass point into the characteristic equation to solve the dynamic characteristics of the heater. The first two vibration modes may be taken.

Explanation of wording in this standard

1 Words used for different degrees of strictness are explained as follows in order to mark the differences in implementing the requirements of this standard.

1) Words denoting a very strict or mandatory requirement:

"Must" is used for affirmation, "must not" for negation.

2) Words denoting a strict requirement under normal conditions:

"Shall" is used for affirmation, "shall not" for negation.

3) Words denoting a permission of a slight choice or an indication of the most suitable choice when conditions permit:

"Should" is used for affirmation, "should not" for negation.

4) "May" is used to express the option available, sometimes with the conditional permit.

2 "Shall comply with..." or "shall meet the requirements of..." is used in this standard to indicate that it is necessary to comply with the requirements stipulated in other relative standards and codes.

List of quoted standards

GB 50011 *Code for Seismic Design of Buildings*

GB 50051 *Code for Design of Chimneys*

GB 50453 *Standard for Classification of Seismic Protection of Buildings and Special Structures in Petrochemical Engineering*

GB 18306 *Seismic Ground Motion Parameters Zonation Map of China*

TSG 21 *Supervision Regulation on Safety Technology for Stationary Pressure Vessel*

AQ 3053 *Safety Technical Code for Vertical Cylindrical Steel Welded Tank*